PLANNING, ESTIMATING AND RATEFIXING

For Production Engineers and Students

BY

A. C. WHITEHEAD

THIRD EDITION

LONDON

SIR ISAAC PITMAN & SONS LTD.

PREFACE

TO THE THIRD EDITION

A LECTURER in Production Engineering inquired recently whether the data in this book were up to date. They are, and I told him so. But, for teaching, would it have mattered much if they were not? Was up-to-dateness with facts and figures ranked higher than training students to understand principles?

Wishing to simplify a calculation for the diameter of a blank for a pressing, I evolved the method shown in Fig. 31. A penknife, a piece of wire, and a knowledge of a beautiful principle in geometry proved sufficient. Three hundred years ago Guldinus rediscovered that principle (which Pappus had enunciated fourteen hundred years earlier), and still it is true, useful, and up to date. But the solid facts, my knife and the piece of wire, are lost.

Besides making several minor alterations and extensions for this edition I have added an Appendix which describes some of the reasons for the *elusiveness of accuracy*. The first part of Chapter X refers briefly to this subject, but it needed supplementing by a more detailed account of the difficulties in producing work free from deformity. Nowadays accurate sizing within fine limits is easy, because attention has been concentrated upon it. The restraint of deformity is much more difficult.

In connexion with that a great part is played by the location of components in jigs and fixtures. It happens, too, that for some years I have felt that location should be studied more academically in order to make it more practical; for it is only by theorizing about observed facts that one can ever become really practical. Writing the Appendix provided me with the opportunity to make

the attempt, and I hope the result will be of equal interest to tool designers and planning engineers.

I call it the Six-Stop Principle of Location. That any component shaped like a matchbox can be positively located on six stops is well known. Five are too few, and seven too many. The six-stop principle holds good for rigid components of any shape. There are no exceptions —in principle. Those who are doubtful are invited to consider the argument and try for themselves the simple experiments which were devised to illustrate it.

A. C. W.

PREFACE

TO THE FIRST EDITION

If you ask a practical engineer how long a new job ought to take, his answer will be "It all depends." Search the libraries and read all that they contain on manufacturing processes, on speeds and feeds, on machines and tools. You will not learn how long that new job should take. Neither will you know at the end whether your regular production is being done efficiently with the facilities you already have.

It is to provide answers to such questions that I have written this book. I have often been asked to recommend one but there was none. This is not to say that there are no good books on some aspects of the subject. There are many.

But how would you concoct a pudding if your cookery book listed half the essential ingredients and gave no clue to the others? No previous works on production, in my opinion, consider properly the manipulating or handling times which occupy *more than half the total* production time in any engineering workshop.

The reference to cookery recipes is not happy if it leads

to the belief that process planning and estimating can be done well by blindly following rigid rules. There are rules; likewise there is scope for imagination and invention, as in other arts. Where practicable I have given rules for quick approximate results, besides more exact methods for students who desire to be thorough and masters of the subject. Where necessary the conventional rules connecting production times with speeds and feeds have been modified. I have also given several original formulae and methods of estimating.

There is scarcely anything conventional about the chapter on Works Economics. It is based on first principles, and explains logically the "how" and the "why" of the building up of production costs. Written from the view-point of a production engineer it will, I hope, help to clear away the mystery which often surrounds them.

The chapters contain hints on workshop planning and machine layouts, including a description of how to arrange for conveyor controlled output. The methods of estimating real, as compared with nominal, productive capacity are also considered, together with capacity charts which I have used successfully in several works.

Reference to the various chapters will show that all the ordinary workshop processes are studied, but no special or proprietary machines. The best way to learn about these is to study the weekly periodicals, particularly the advertisements. Desiring the book to be compact, for convenient reference and intensive study, I have omitted matter which can be obtained satisfactorily and easily elsewhere.

The words "Production Engineers and Students" in the title refer to mechanics, draughtsmen, estimators, ratefixers, planning engineers, cost accountants, foremen, managers, and others who now control, or who will one day, control production. What I have written I know to be true, and I have tried to be so definite and clear that there is no ambiguity anywhere.

the attempt, and I hope the result will be of equal interest to tool designers and planning engineers.

I call it the Six-Stop Principle of Location. That any component shaped like a matchbox can be positively located on six stops is well known. Five are too few, and seven too many. The six-stop principle holds good for rigid components of any shape. There are no exceptions —in principle. Those who are doubtful are invited to consider the argument and try for themselves the simple experiments which were devised to illustrate it.

A. C. W.

PREFACE

TO THE FIRST EDITION

If you ask a practical engineer how long a new job ought to take, his answer will be "It all depends." Search the libraries and read all that they contain on manufacturing processes, on speeds and feeds, on machines and tools. You will not learn how long that new job should take. Neither will you know at the end whether your regular production is being done efficiently with the facilities you already have.

It is to provide answers to such questions that I have written this book. I have often been asked to recommend one but there was none. This is not to say that there are no good books on some aspects of the subject. There are many.

But how would you concoct a pudding if your cookery book listed half the essential ingredients and gave no clue to the others? No previous works on production, in my opinion, consider properly the manipulating or handling times which occupy more than half the total production time in any engineering workshop.

The reference to cookery recipes is not happy if it leads

to the belief that process planning and estimating can be done well by blindly following rigid rules. There are rules; likewise there is scope for imagination and invention, as in other arts. Where practicable I have given rules for quick approximate results, besides more exact methods for students who desire to be thorough and masters of the subject. Where necessary the conventional rules connecting production times with speeds and feeds have been modified. I have also given several original formulae and methods of estimating.

There is scarcely anything conventional about the chapter on Works Economics. It is based on first principles, and explains logically the "how" and the "why" of the building up of production costs. Written from the view-point of a production engineer it will, I hope, help to clear away the mystery which often surrounds them.

The chapters contain hints on workshop planning and machine layouts, including a description of how to arrange for conveyor controlled output. The methods of estimating real, as compared with nominal, productive capacity are also considered, together with capacity charts which I have used successfully in several works.

Reference to the various chapters will show that all the ordinary workshop processes are studied, but no special or proprietary machines. The best way to learn about these is to study the weekly periodicals, particularly the advertisements. Desiring the book to be compact, for convenient reference and intensive study, I have omitted matter which can be obtained satisfactorily and easily elsewhere.

The words "Production Engineers and Students" in the title refer to mechanics, draughtsmen, estimators, ratefixers, planning engineers, cost accountants, foremen, managers, and others who now control, or who will one day, control production. What I have written I know to be true, and I have tried to be so definite and clear that there is no ambiguity anywhere.

CONTENTS

INSETS

PLANNING, ESTIMATING AND RATEFIXING

CHAPTER I

INTRODUCTORY

THE object of planning manufacturing processes in detail is to arrive directly at the most economical methods of production. When the quantities of similar parts to be made are large, the methods which consume the least workshop time are usually the most economical; but this is less frequently true of smaller quantities.

Operation times decide the quantity of plant and labour required for a given rate of output and are a guide to, if not an absolute measure of, operation costs. In all cases an operation list precedes the complete plan and shows the sequence of operations, without any details which indicate how or at what speed they are to be carried out. Such a list is useful for tool designers and for routing work through the shops. It indicates serviceable methods which will succeed in producing components of the desired quality even though they may be unduly expensive; that is, of course, if it has been skilfully planned.

A master layout defines a procedure which is ideal but practical. It states what is to be done and exactly how and by what means; it takes into account the facilities which are available but makes no allowance for imperfections which can be removed and ought not to be tolerated. Hence a competent planning department which prepares these layouts has a strong energizing influence. By its work the hosts of faults which are continually retarding production are clearly shown up and steps directed to their elimination.

This is not to say that inconvenient dispositions of the work or awkward arrangements of any kind should be allowed. The duty of the planner is to assume rightness in such minor details and to point out to the shop supervisors any defects which they have failed to remedy while putting his schemes into practice.

In every process certain groups of motions are always associated together and can be classified. Raising and lowering the drill spindle during drilling operations, exchanging drills and other tools, setting work in a fixture and removing it when it has been dealt with are examples.

All such associated movements can be studied, classified and timed under various conditions. For the present purpose they will be termed *constituents*. They are not elements for they are not even fixed as regards the group of motions contained in them. Like operations they may contain whatever is most convenient at the time for the purpose in view. And the word *constituent* is not used for anything else likely to cause confusion.

For the present purpose, then, the production of a finished component from the raw material is carried out by making it undergo a series of processes; each process is made up of operations; each operation is the sum of its constituents and each constituent can be analysed into simple motions.

Not only do constituents consist of simple motions but they usually include a complete cycle; that is, a return is made to the starting point. This is frequently obscured by the way in which the constituents are interwoven, one being interrupted while several others, perhaps, are partly or wholly completed. For example, work is placed on a table but removed after it has been operated upon; tools are inserted in their holders but taken out after use; a machine table is slid along for safety or convenience while components are being exchanged in a fixture but is returned after the exchange has been made; a man picks

up a rivet, does his work upon it, then returns to pick up another. There obviously must be a forward set and a return set of motions wherever the work is repetitive, and the constituent may include both although only the forward set is named. Thus *Load fixture* is a constituent part of an operation and, unless otherwise stated, will mean *Load and unload fixture.*

If an operation be completely analysed into constituents for which the proper performance times are known the total time which the operation should consume is also known for it is the sum of the constituent times.

Granting this to be true, will the constituent times in one works apply equally in others? Investigations widely made show that there is no appreciable difference in the speed of working in different parts of the country as regards the constituents when the conditions are similar. The only conditions which need be taken into account are those which cannot be controlled by works management, namely, the massiveness of the product and the quantities made.

In those workshops where the average component weighs many pounds, and cranes are in regular use in the machine shop, the speed of the operators is slower on those components which weigh only a few ounces than it is in workshops devoted exclusively to light work. There is no regular relation between the speeds but often the constituent times differ in the ratio of 3 : 2 in favour of the light component specialists. Note that constituent times, not operation times, are compared. Whereas a comparison of constituent times is easy and can be made in any two works or neighbouring machines engaged on dissimilar components in one works, it is difficult to find exactly parallel operations. Either the machines, or the components, or the materials differ; there are too many variables for it to be certain how to make an accurate comparison at all. But constituents such as indexing a 6-inch capstan or raising and lowering the spindle of a

sensitive drilling machine contain the same group of movements always. Consequently, if exceptional cases are discarded the manipulating speeds in different works can be fairly compared. Constituents which depend on the machine and not handling are just as efficient in one as the other type of works except that men surrounded by heavier production seldom use quite the maximum possible speeds on small brass and aluminium parts, whereas they soon would if segregated.

On the average it takes an operator engaged in intensive production three or four weeks to attain full speed. Hence those who have small quantities to operate upon and frequent changes to make are comparatively slow workers. The machines will do their part quite well but the operators get insufficient practice to move without mental strain. They consciously direct their motions instead of performing them automatically. Yet the method of constituent times enables a skilful planning engineer to forecast operation times with small risk of a large error even in such cases. In fact there can be little wrong with a well-made process layout even if the results in the works prove inferior to expectations. Occasionally the results are better, of course, because circumstances are exceptionally favourable now and again.

A well-made master layout depends for its operation times on standard constituent times to which have been added special allowances to suit the circumstances. When the actual results in the shops are not in accord there may be extraordinary conditions which could not have been anticipated and which cannot be changed; there may be data to collect for future guidance; and any investigation will certainly reveal imperfections which can be wholly or partly eliminated. Perfection is always out of reach.

Although exceptional operators vary by at least 20% above or below the average in manipulative speed, the great majority are not far from the mean rating; and if the observed time of an operation exceeds the scientifically

forecast or standard time it is due in nearly every instance to one of the following—

(1) Operator's clumsiness, which may be through want of practice or physical unsuitability.
(2) Making useless movements or doing work which is not required.
(3) Extra work is found desirable to improve the component although it was not originally expected to be required.
(4) Feed and speed combination is too low.
(5) The material is unsuitable or not as specified, or tools are inadequate, or the general conditions are unsatisfactory.
(6) The operator is not "playing the game."

Five of these items can be controlled by works management; the third requires an amendment to the layout. By comparing the actual performance with the ideal performance which the layout specified it is possible to detect in which constituents the operator is at fault, or where the shop management has failed. Many of these faults will not be suspected, let alone detected, if reliance is placed on shop supervision alone for efficiency.

It is impossible to make rules or formulæ which will entirely eliminate the need of some judgment in applying them. And planning is one of the arts. Practice with paints and brushes and the study of pictorial composition for 30 years will not make an ungifted man into an artist: neither will 30 years' experience in first-class workshops necessarily result in planning ability of a high order. The vital quality of imagination is necessary as well as opportunity and perseverance.

The constituent times for intensive production work in full swing will be taken as standard in the following chapters. On repetitive work which is new to the operator though he is used to the shop and the process it will be found, on the average, that his handling times will exceed the standard times by 50% during the first week, 25% the

second week and 10% the third week. If the process is also strange these percentages may be doubled. When the work is intricate or very fine the "learning" period will be longer. On the other hand extremely simple operations such as sensitive drilling or flypress operating may be learnt in a week and a $33\frac{1}{3}$% allowance is adequate.

The start of an operation is always slow; it takes time to get into the swing. When the business is quite strange an observation of the speed at the start gives little indication of what the ultimate rate will be.

In the case of a machine of a new type for a special lapping operation the output averaged 35 components a day after a fortnight: a month later the output was 50 a day: at the end of three months 100 components a day were easily dealt with. At first the operators' control was uncertain and they lacked confidence. It was not until they were sure of what was required and made their adjustments and movements automatically that their speed was satisfactory.

Although there is justification for handling times to be above the standards when the quantities to be made are small, there is little reason for adjusting cutting times. Speeds and feeds should be correct from the start. Yet it is found that operators are often timid in this respect at the commencement; they will even drill holes at low speeds to make sure that they are good ones.

If in any works it is found that the standards based on the constituent times which are given in succeeding chapters are unsuitable and that the special circumstances are not covered by the recommended adjustments it will be easy to find and make others. For example, in a few works the finish and accuracy is kept at an extraordinary high standard. To suit this some of the finishing processes will need perhaps 50% more time for handling and machining. The machining times will be affected if extremely fine feeds are used for the sake of appearance; but the greatest difference may be found in assembling

speeds due to the extra care in handling to prevent scratches and other blemishes and in making fine adjustments.

However, once the right standards have been found no further alterations will be needed unless the conditions are changed. Consequently, operation times may then be built up from the data with the certainty that they will be accurate.

It is the business of the production engineer to produce efficiently: he cannot do this while swayed by belief in fine-sounding but misleading slogans. The saying that "a new machine ought to pay for itself in a year" has cost many a firm thousands of pounds. "Night work does not pay" is another half-truth. There are many who believe that the labour cost of an article should be practically unchanging. There are many more who will enthusiastically save £1 a week on direct labour but spend £5 a week extra in the tool room to get it, and believe they have economized because "overheads are so much per cent on labour."

There is too little collaboration between production engineers and cost accountants. Closer association would help both parties: the accountants would learn to visualize better the facts their figures stand for and the engineers would understand more deeply the economic results of their activities. Accountants tend to become too conservative. Production engineers should be able to counter this by looking far ahead and backing their arguments for enterprise with convincing figures.

CHAPTER II

RATEFIXING AND TIME STUDY

Floor to floor time is the interval of time between picking up the component and depositing it after the operation upon it has been completed. It is not the same thing as basic or operation time although the two are often confused. The symbol FFT will often be used for the term floor to floor time.

Floor to floor times are generally quoted by machine tool factors to give their customers an idea of what output is likely to be obtained from the machines being considered. Rate fixers generally have little opportunity for studying how the FFT is made up. Although it looks an easy job it requires considerable skill and patience to make time studies properly.

Hurried observations may be misleading because they include less work than is actually involved in a complete operation, or even in the true floor to floor time. Every floor to floor time includes a complete cycle; that is, the operator and the machine return at the end to exactly the same positions they were in at the start. The starting point is often the pick up of the component. It is not always the best one to choose. There is perhaps at some part of the cycle a sharp click or a swift plain movement which gives a very reliable datum point. Both the risk and effect of observational errors are diminished by observing several consecutive cycles. The longer observations will probably show that there is work to be done which occurs only at intervals but which is part of the true cycle and must be reckoned in it. This is generally the case with small components of which the operator will, at intervals, take a quantity from his bulk supply and place ready for quick handling. Other examples are feeding a fresh bar in capstan work, or clearing

away an accumulation of swarf in milling or press operations.

When the rate fixer has arrived at a correct floor to floor time, either by observation or from the planning engineer's estimate, he is in a position to fix the operation time and to bargain with the operator. As a rule the operation or basic time will be the FFT plus an allowance for tool attention, an allowance for fatigue and personal delays and possibly some addition for other delays such as waiting for a crane. (See Fig. 51 for graphic representation.) The operation time is the basis on which the payment for the work will be calculated and agreement between the rate fixer and the operator concerned must be reached or no contract for payment by results can be made. Unfair contracts must be avoided. If the basic time is fixed too high either the operator will earn more than is fair, or what is worse, he will restrict the output; if it is too low the operator will be demoralized and probably restrict his output still more.

The method of constituents is the only safe way of arriving at fair basic times. When it is more widely and skilrully used less will be heard of the numerous schemes which have been devised to improve on straight piece-work. All of them spring from one cause and that is unfair basic times. None of them is so generally satisfactory as a well administered piece-work or piece-bonus system.

In all bonus systems the workman receives his day rate and is paid extra for doing an agreed-upon amount of work in less than a stated time. Where piece-work conditions are strictly maintained the workman is paid only for the work he does, no mat·er how long he takes over it.

The Halsey and Rowan bonus systems are well known. In the former the workman contracts to do a stated amount of work in a given time, if possible. If he does it in less than the given time he is paid for the time he takes and a part (usually half) of the time he saves. Thus, if

he is given 36 hours to do a job and does it in 24 hours he would be paid, at day-work rate, for

$$24+\frac{36-24}{2}=30 \text{ hours.}$$

By the Rowan system the effect is that the man earns time and a third if he saves one third of the time allowance, time and a half if he saves half the time allowance and so on, the enhanced rate being paid on the time taken. If a a man were allowed 32 hours and took 24 hours, thus saving 8 hours (which is one-fourth of the 32 hours) he would be paid time and a quarter for 24 hours, or 30 hours. When on piece-work the man would be offered 30 hours (or the equivalent in money) for the same job and if he did it in 24 hours would, as before, earn time and a quarter. If the time taken were not 24 hours there would be differences in the man's earnings by the three systems. It is these differences which are supposed to give the Halsey, Rowan and similar systems their special merit. But the extra clerical work involved has to be paid for. It is a fallacy to think that men will work so fast as to risk having their allowances or prices cut. If the basic times are right the average man's earnings by any system will be the same.

Fig. 1 compares graphically results by each system for different speeds of working. The basic time, is represented at A by the open rectangles, piece-work at the top, Halsey next and Rowan underneath. The shaded areas represent the appropriate allowances to enable a man to earn time and a quarter. It is least for piece-work and most for the Halsey plan. At B is shown the man's extra earnings for doing the work in the basic time. The black areas are the extra earnings and they are equal for all three systems. If the man takes three-fourths of the basic time he gets the full amount for piece-work, as before, but less by the bonus methods of payment as shown by the black areas at C. But if he takes 25% more than the

basic time he receives more by both the Halsey and Rowan plans than for piece-work. In general the Halsey and Rowan systems have a retarding effect on the quick workers. They feel they would not get quite all they earn if they should do their best.

There are two distinct ways of arranging piece-work

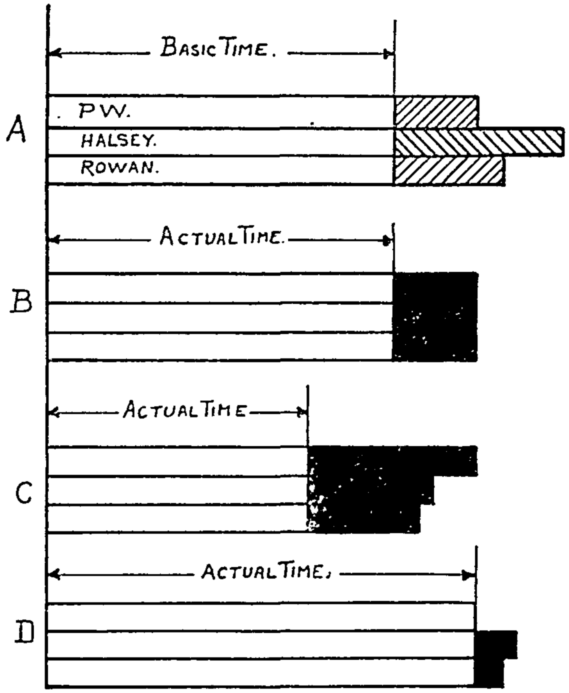


FIG. 1. BONUS EARNINGS

payment: one is calculated on money prices, the other on time. The latter is sometimes called piece-bonus instead of piece-work and is gradually ousting the money basis. In either case the real basis is time, for the money price is calculated to give what is considered to be the fair payment for work which will normally take a certain amount of time to do.

When a money price is fixed for a job the price remains unaltered whether a skilled man or a youth does it. At least, it is so in theory. In practice, adjustments are made

to prevent earnings which would be absurdly low for a man or far too high for, say, an apprentice.

The principal advantages of the piece-bonus system are that it renders the rate fixer's and all other calculations easier and provides for variations in basic rates of pay (that is, the nominal day-work rates) with different operators, or at different periods. For example, if a boy rated at 6d. an hour could work as fast as a man rated at 1/- and the man earned time and a quarter, or 1/3 an hour, the boy also could earn time and a quarter, i.e. 7½d. an hour. But obviously the work would then be a boy's job.

This brings up one of the defects of the system: it makes necessary a grading of labour and the right grade must be employed on specified work.

The three main classes are girls, boys and men. These are usually subdivided into about three grades for girls and for boys according to their ages and rates of pay. Similarly, men are graded according to their skill and rates of pay into three or sometimes four divisions. A system of symbols is devised (usually letters of the alphabet and numerals) for indicating concisely on all the papers relating to the matter which grades of labour should be employed on the various operations. Were there not this control the costs of production might soar, for it is much easier to get most kinds of production at the required rate from men than from girls or boys and their pay is, roughly, double that of the latter. It is also necessary to use the specified grade of men for any class of operation for the same reason; the skilled and higher rated men being, on the whole, less trouble to manage and quicker at picking up fresh operations than others would be preferred by foremen were costs not watched. Ordinary piece-work where money prices are fixed avoids this trouble. On the other hand it makes the reverse process, lowering the labour cost, more difficult.

A stable labour cost is preferred by some on the ground

that the production cost is thereby fixed. As will be indicated later this is not necessarily true, though it may appear to be so by the costing method employed.

When the basic operation time has been provisionally settled the next business is to calculate the piece-work time or price. If money prices are given they are most conveniently based on operating on either one or a dozen articles. This is not absolutely necessary but it is as well not to have miscellaneous quantities because of the confusion likely to arise. A price based on one piece is suited to long operations and on a dozen to short ones (because there are twelve pence to a shilling).

Suppose a rate fixer has been advised, or has come to the conclusion by observation, that a reasonable basic time for an operation on 12 articles is 43 minutes (awkward figures are chosen for the example because they occur in practice), what should be the piece-work price for a man whose grade of labour is rated at 35/- for a 47-hour week?

The standard bonus allowance for piece-work earnings is 25% of the day rate, though in some works a higher allowance is the rule. Thus a man in receipt of 35/- for 47 hours day work (ignoring cost of living or other allowances which do not rank in piece-work) would be expected to earn £2 3s. 9d. a week when employed on piece-work.

The basic time for a dozen components being 43 minutes, reference to a ready reckoner shows this to be worth 6½d. for a man rated at 35/-. The addition of 25% gives 8d. as the piece-work price. To save repeated calculations the rate fixer should be supplied with or construct for himself a table, showing for the various rates of wages with which he is concerned, the equivalent money prices for minutes and hours, with the 25% (or whatever it may be) already added to the basic rate.

The accompanying piece-work conversion table illustrates a convenient arrangement. It may be extended to include whatever wage rates are in vogue and to save

PIECE-WORK CONVERSION TABLE

Basic Rate P.W. Rate	25/– 31/3	30/– 37/6	35/– 43/9	40/– 50/–	45/– 56/3		25/– 31/3	30/– 37/6	35/– 43/9	40/– 50/–	45/– 56/3
Minutes						Hours					
1	0·13	0·16	0·19	0·21	0·24	1	7·98	9·57	11·17	12·77	14·36
2	0·26	0·32	0·37	0·43	0·48	2	15·96	19·15	22·34	25·53	28·72
3	0·40	0·48	0·56	0·64	0·72	3	23·94	28·73	33·51	38·30	43·08
4	0·53	0·64	0·75	0·85	0·96	4	31·92	38·30	44·68	51·06	57·45
5	0·66	0·80	0·93	1·06	1·20	5	39·89	47·87	55·85	63·83	71·81
6	0·80	0·96	1·12	1·28	1·44	6	47·87	57·45	67·02	76·60	86·17
7	0·93	1·12	1·30	1·49	1·68	7	55·85	67·02	78·19	89·36	100·53
8	1·06	1·28	1·49	1·70	1·91	8	63·83	76·59	89·36	102·13	114·89
9	1·20	1·44	1·67	1·91	2·15	9	71·81	86·17	100·53	114·89	129·25
10	1·33	1·59	1·86	2·13	2·39	10	79·79	95·74	111·70	127·66	143·61
20	2·66	3·19	3·72	4·26	4·78	20	159·58	191·49	223·40	255·32	287·23
30	3·99	4·78	5·58	6·38	7·18	30	239·37	287·33	335·10	382·98	430·84
40	5·32	6·38	7·45	8·51	9·57	40	319·16	382·98	446·81	510·64	574·46
50	6·65	7·98	9·31	10·64	11·96						
60	7·98	9·57	11·17	12·77	14·36						

the need of addition for intermediate times, as desired. As the table stands the piece-work price equivalent for 43 minutes is not given direct and has to be got by adding the figures for 3 and 40 minutes.

40 minutes at 35s. rate	. . .	7·45
3 ,, ,, ,, ,,	. . .	0·56
43 ,, ,, ,, ,,	. . .	8·01

The prices are all given in pence and decimals of a penny, that being better than working in farthings, though the nearest farthing is taken, of course, at the conclusion.

When the value of the work is expressed in time, the time may be for single components, or tens, or the quantity done per hour. In any case the calculation is extremely simple.

If the basic operation time is 9 minutes for 1 component the piece-work time will be 9 plus 25% of 9 minutes which equals 11.25 minutes. Alternatively, the quantity done in 1 hour may be the basis. For example, if 34 components can be operated on in 60 minutes, the piece-work time will be 75 minutes for 34 components. This leads to rather intricate arithmetic for the operator when he is making up his own account of the pay due to him. Suppose he has done 321 components, for instance, at 75 minutes for 34. It is best to keep to times per component (or tens, or hundreds). Also for this purpose the best unit of time is the minute. An exception may be made for exceedingly lengthy operations but if an hour is the unit the fact must be clearly stated.

At the end of the week the operator adds up the minutes he has earned and this total entitles him to exactly the same pay as if each job had been given a separate money price.

The next business is striking a bargain with the operator. Whatever opinion the rate fixer has on the matter the operator may have a different one. Each will present his

view. In most cases the discussion will be short and the arranged price (or time) will be very close to that which the rate fixer had in mind at the start. A discussion is always valuable if it does not descend to haggling. It is easily possible for a planning engineer or a rate fixer to have overlooked some difficulty which the man has foreseen, and a man dissatisfied with a price is unlikely to yield his best efforts. The rate fixer should offer at the onset the price he considers just. Offering less is weakness. It develops haggling and suspicion. To offer more would be ridiculous. If an agreement between the rate fixer and the operator cannot be reached, the job is paid for at day-work rate. This is a rare occurrence.

A contract note is made out when the price is agreed. One copy is given to the man, one copy is usually sent to the cost office and a third copy is kept by the rate fixer (or in the central ratefixing office) for future reference. At the end of the week, or as soon as the work is completed, the man's note goes, via the inspector who certifies the quantity of work he has done correctly, to the wages office. His foreman usually sees the note and initials it. This is the general routine followed in most works. There is one variation practised where repetition work is the rule: the man is not given a copy but may see, at any time he wishes, a copy of the contract which was made originally on the terms he is expected to accept. Of course he is allowed the same price for the work and the quantities he does are certified in the usual way. What is saved is the useless repetition of contract notes, ordinary inspection and time recording being all that is required unless a change is made in the price.

Most works managers will inform an inquirer that "we never change a price in our works unless the method is changed." And each will believe that to be almost a unique state of affairs. The unfortunate fact is that methods are sometimes changed without improving them solely with the view of reducing wages; for every rate

fixer misjudges occasionally and allows an extravagant price. Any price may be changed by mutual agreement between the rate fixer and the operator, up or down. This is the fair way of approaching all unsatisfactory contracts. But sometimes the fair way is not practical and a change of method is necessary. In that case the change should be complete and, if possible, it should involve several other operations unless a minor alteration will really effect a substantial saving in the time taken by the one it is desired to reduce. High wages may be a sign of an exceptional operator, not of a rate fixer's error. If that is the case there should be no reduction—an increase would be more justifiable.

Since every operation is made up of constituents, and the times which these take can only be found by observation, it is a pity that rate fixers generally have not the time or do not endeavour to study them. If constituent times are desired it is usually necessary to send a man into the shops for the special purpose of observing them. Perhaps it is as well. The rate fixer should be a practical man who can hold his own with other men, whereas the qualifications necessary for making reliable observations of constituent times are—

(1) Ability to observe and note quick movements in rapid succession and to time them separately.

(2) Sufficient practical knowledge of the workshops to understand exactly what is needed and not to be misled by men or circumstances.

As a rule the rate fixer's training has not developed the first in a scientific way, and in the hurly-burly of production there are not many who have the time or would be encouraged to make such observations. But, when possible, every observation of an operation should include its main constituents at least. In general these are *Loading* (remembering that this, as in all similar cases, also implicates the reverse motions), *Manipulating* and *Cutting* (or whatever the object of the process happens to

be). These alone provide valuable information for future guidance if records of data are kept in order.

An observation of a single floor to floor cycle may inclued business which occurs infrequently or which should not occur at all; it is likely to mislead because of wrongful inclusion or exclusion unless it is carefully analysed and the various constituents are examined. The following example will make this clear. A small component was being drilled and reamed on a single spindle sensitive drilling machine. The jig had slip bushes to suit the drill and reamer respectively and a quick-change chuck was used.

Observed FFT for three components were—

Component A	77 seconds
,, B	92 ,,
,, C	82 ,,
Total	251 seconds
Average	83·7 seconds

An analysis of the FFT for component A showed it to be made up by

1. Loading	30 seconds
2. Manipulating jig and drill	2 ,,
3. Drilling	10 ,,
4. Manipulating slip bushes, etc.	12 ,,
5. Manipulating reamer	7 ,,
6. Reaming	6 ,,
7. Gauging	10 ,,
	77 seconds

At this stage it will be as well to detail exactly what the above constituents include—

(1) Locating and securing component in jig; removing it after completion and cleaning jig.

(2) Placing jig under drill; lowering and raising the drill before and after cutting.

(3) Drill-cutting time.

(4) Exchanging reamer for drill and reamer bush for drill bush.

(5) Similar to 2 but for reamer.
(6) Similar to 3 but for reamer.
(7) Gauging the hole with a limit gauge.

For components B and C the records were—

	B	C
Picking up 5 components and placing handy .	7	–
Exchanging slip bushes and the drill for the reamer	10	–
Load (same as 1)	26	29
Manipulation (same as 2)	2	2
Drilling (same as 3)	9	10
Manipulation (same as 4)	12	12
Manipulation (same as 5)	6	6
Reaming (same as 6)	8	6
Gauging (same as 7)	–	4
Exchanging slip bushes and the drill for the reamer	12	13
	92	82

Now although the observation on A includes the time from picking it up to depositing it when finished, the cycle was not complete. Omissions of this kind are easy, and those who are not experienced in the business and "take out their watch to see how many the fellow can do" are extremely likely to be wrong. "I saw him do it in 77 seconds." Yes, but the reamer was still in the chuck; there would have to be exchange of slip bushes, too. On the other hand the time of 92 seconds for B is swollen by two items. The picking up of 5 components should be shared among 5. Infrequent constituents like this must be reckoned, yet can very easily be missed in a short observation. The other item which inflates the time for B is the duplication of the constituent which was left out of A's record. Exchanging slip bushes and the drill for the reamer occurs twice.

But example C is fair. If that alone had been observed it would have given a sound basis on which to fix an operation time. An examination of the remaining constituents shows no strange variations with the exception of the gauging time. Apparently, gauging every component was not necessary as no time was spent on B for

this purpose. The records gave no indication of why A took 10 and C only 4 seconds to gauge. That might be something to investigate.

Studies like the above often reveal errors of a very different kind: they may be used to detect faults and deception. It is a fact that unpractised operators will occasionally make deft movements, and the man who wishes to deceive by retarding an operation during an observation will rarely do it consistently through several cycles. Sometimes he will fumble this and sometimes that; in the course of one cycle he will appear to have trouble with constituents which are performed smartly during others. Inconsistency in the performance times of the constituents is a sure sign of something or somebody requiring correction. The fault may be with the operator or with his tools or with the components he works on; in any case investigation will be profitable.

An observer soon learns that the fastest workers always appear to have a good deal in reserve. Speed is closely allied to dexterity and is far removed from hustle and bustle. This may seem queer; but a little reflection will show how universally this statement applies to high skill in sport as well as handicraft. It is particularly in evidence in processes such as light assembling which depend mainly on manipulative skill. The greater the skill of the performer the more lucky he appears to be in missing the troubles which beset the majority.

Not infrequently operators are unable (really unable) to work at a desired speed, because they are convinced that it is impossible. Their foreman may hold the same opinion. The best remedy is demonstration. This is well illustrated by an experience with ten young men operating capstan lathes. All were doing the same job on first-class, well-equipped machines, and no amount of drive or persuasion could obtain more than 70% of the expected output.

In ordinary circumstances the management would have

provided extra machines, but the personal pride of the man most responsible was involved and he arranged for the best turner in the works to operate one of the capstans for a few weeks.

As always with first-class men, this operator did the job in a way which looked casual and easy-going but was very fast. Not to be beaten, his fellows competed, and within three weeks their output was satisfactory.

Many examples of this kind could be given. Those who attend sports meetings can often see the "I can't" look on a high-jumper's face as he takes his run. With that look, with that inner feeling, he is beaten before he jumps.

Electrical resistance coils for heating elements are often wound on long thin mandrels. These mandrels are chucked at one end, supported at intervals by steadies, and the tail end is held in a rotary sleeve in such a way that tension exists in the mandrel to minimize whirling when it is running at about 1,000 r.p.m. The machines are similar to small centre lathes and are driven either by small electric motors or by belt from a shaft. In either case there is pedal control of rotation in order to leave both hands free to tend the wire and shift the steadies as requisite. One end of the wire is secured to the chuck; when the mandrel spins the wire is drawn upon it to form a close coiled spring, perhaps 48 inches long with a core diameter of $\frac{5}{32}$ inch. The wire is guided entirely by hand. A little practice proves that it is a much easier job than would appear, but one where individual skill varies considerably. The moment a fault occurs winding is stopped by the release of the pedal (either by breaking a switch or by releasing a friction clutch) and is resumed after correction.

A record is given below of an observation on five consecutive cycles of winding by which five coils were produced. For the purpose of studying the operation it was divided into constituents thus—

A. Take up mandrel, chuck ends, arrange steadies and fix wire to chuck.

B. Start winding slowly (by working the pedal on and off) for a few turns.

C. Wind the length at full speed (subject to faults and corrections).

D. Stop. Cut wire and twist end to prevent helix from coming undone.

E. Remove mandrel with coil from machine, slip coil off mandrel and lay it on bench.

These constituents are all fairly complex but yet sufficiently simple to discover the information which was desired.

Constituents	Cycles					Averages
	1st	2nd	3rd	4th	5th	
A . .	36	40	30	32	38	35·2
B . .	5	6	10	7	6	6·8
C . .	48	50	82	74	65	63·8
D . .	18	14	10	10	12	12·8
E . .	30	27	28	34	38	31·4
Totals .	137	137	160	157	159	150·0

On the whole the cycle times vary too much from the mean to be satisfactory considering that the operator was experienced. Some variations will occur in observed times because the demarcations between the various constituents are indefinite; but this will not affect appreciably the overall cycle time observation. A study of the constituent times discovered the major cause of the excessive times occupied by the last three cycles.

Constituent A. Cycles 2 and 5. In both cases slight trouble, possibly excusable, in fixing the wire to the chuck accounted for delay.

Constituent B. The start was always wary to prevent either lapping or open spaces between coils. By gently depressing and then releasing the pedal the operator

could make the first few turns at a low speed. In the third cycle the start was unusually prolonged without any obvious reason.

Constituent C. In this a variation was to be expected if there were recurrent faults to be corrected. There was nothing obviously troublesome or wrong except the variation in time.

Constituents D and E. Although the variations were too great to be satisfactory there was nothing very definite to criticize.

What, then, was the explanation? Since there were no hitches in constituent C yet the time taken varied from 48 to 82 seconds, the actual winding or r.p.m. must have varied. There could be no other reason. Under the bench on which the winding machine was mounted there were boxes containing various components. When these were removed and a clear view of the pedal working was obtainable the problem was solved. By skilful use of the pedal the operator could run the machine at a fairly constant speed well below the maximum. And that was the reason for the false times.

There is another and very valuable way of guarding against misleading observations. It must be used judiciously or it may be unfair. For computing a fair cycle time in the above case the inflated times should be struck out. But since the retention of only the low times tends occasionally to give too small a total, the high times should be replaced by the average figures. Conspicuously low constituent times in any cycle are usually the result of incorrect recording and should also be replaced in the same way. The average times may be expressed in the nearest round figures as shown in the adjusted table on page 25.

The new average on the adjusted basis is 138·6 seconds.

The reduction is not great, only about 7%; but any justifiable saving, however small, is worth while.

When work is being done briskly, and every one engaged

Constituents	Cycles				
	1st	2nd	3rd	4th	5th
A . .	35	35	30	32	35
B . .	5	6	7	7	6
C . .	48	50	64	64	64
D . .	13	13	10	10	12
E . .	30	27	28	31	31
Total . .	131	131	139	144	148

appears to be industrious, it is rarely easy to convince superintendents that substantial improvement may be possible. Too often energy is frittered away in unprofitable business. The next example is an illustration of this.

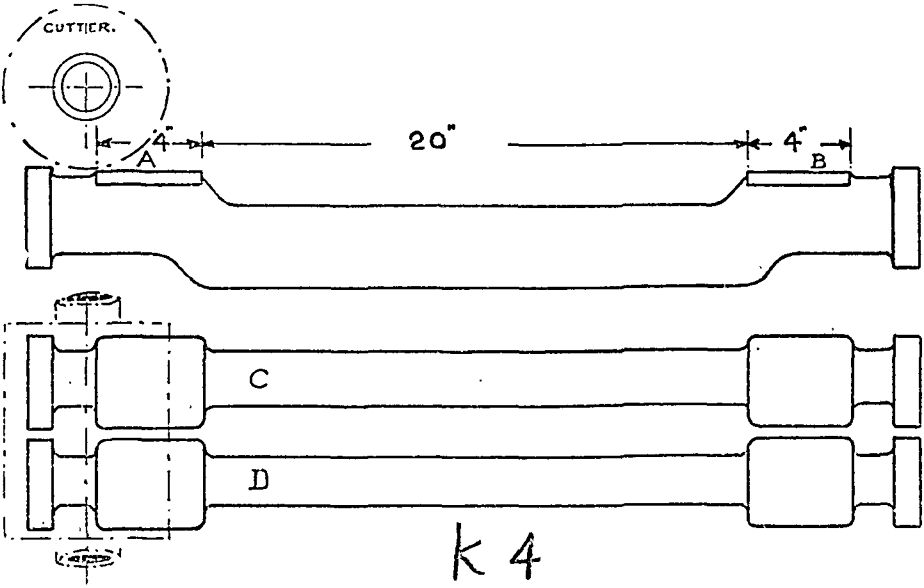
A machine operation took, on the average, four minutes to complete. Ten girls attending to ten machines were fully engaged on it. The section bore a good name for efficiency and was undoubtedly hard working. Yet a casual observation followed by a little rearrangement increased the output per machine by nearly 80%.

The observation showed that the actual floor to floor time was barely two minutes. This was incredible. A thorough study was made, a girl of medium ability being the subject, in order to obtain dependable figures. It was found that when a few components had been completed she carried them in a tray to the inspector's table. Next she would prepare her supply of materials, frequently having to visit the sub-stores, where the bulk was kept, and wait her turn to be served. The cure was obvious, namely the employment of an extra girl to save the others from running about, and a better stores service. In this way the increase of output was easily maintained. Moreover the waitress had time to do other useful work besides. Niggardliness in providing labour of this kind is a common fault, being encouraged because it saves wages which many regard as non-productive. If efficiency is sought the

X. 89P

idea of productive and non-productive labour must be firmly dismissed. There is direct labour and indirect labour. A wise combination of the two gives the most profitable results, the whole of the labour being helpful.

Fig. 2 shows a pair of forgings to be milled on the faces



K 4

FIG. 2. MILLING A PAIR OF FORGINGS

A and B. They are held in parallel as at C and D on a fixture; the sizes are stated in inches; the material is 40-ton steel and about $\frac{3}{16}$ inch is to be removed in one cut.

58480

An observation of four consecutive cycles gave the results tabulated on page 27.

The outstanding time for the third cycle was due to clearing away accumulated swarf. A partial clearance was made at every cycle and a thorough cleansing for every fourth pair of components.

Nearly 40 seconds per component for swarf clearance is grossly excessive. The period of 71 seconds for loading and unloading is rather high, too. In fact there is nothing quite satisfactory about any of the constituents, although the operator was undoubtedly competent and industrious.

Constituents	1	2	3	4
Unload 2 components	40	45	30	35
Clean away swarf	40	30	210	30
Load 2 components	90	120	105	105
Adjust cutter, etc.	25	30	30	30
Mill faces A	175	165	170	170
Wind table for faces B	20	25	20	20
Mill faces B	165	185	170	175
Raise cutters	25	25	30	25
Return table to start	15	20	15	15
	595	645	780	605
FFT per component	297	322	390	302

Yet it would scarcely have paid to make changes unless the quantities to be machined were large. If a machine has been equipped at considerable expense the possibilities of very substantial savings must be apparent before radical changes can be made on economical grounds. It is generally easy to improve on any operation as regards time, and not so easy to do it so that it will not actually waste money. Or, to put it another way, there is no real economy in saving 1,000 hours in the machine shop if 2,000 hours have to be expended in the tool room in order to effect it.

Out of an average FFT of 330 seconds per component the constituent times were, in round figures—

Clearing away swarf	40 seconds
Loading, etc.	71 ,,
Winding table	19 ,,
Adjusting cutter height	27 ,,
Cutting	172 ,,

One naturally thinks of a cutting operation as being principally devoted to cutting. Yet, as in this example, it is common for the incidentals to amount to nearly half, and often more than half, of the whole cycle time. An increase in cutting speed or feed may easily defeat its object because of extra cutter grinding (involving labour in another place) and machine delay in exchanging

cutters. Generally speaking, unless there is obvious need for alteration, speeds and feeds should not be attacked first.

In this case no great improvement could be made without a heavy expense. A vertical milling machine would have been an improvement yet would not have avoided the swarf trouble. It should be noted that the operator had other duties to perform, so could not clear away chips during cutting time. Again, the 27 seconds per component for adjusting cutter height was necessary because the components could not be inserted in the fixture without plenty of clearance. This points to face milling working from the centre outwards for both ends as being the right method. Then, remembering that face milling with a horizontal spindle could be arranged so that the swarf would fall quite clear of the fixture into a receptacle from which a labourer could take it at intervals, one is led to the conclusion that face milling on a horizontal machine is the best method if the component can then be easily lifted into and out of the fixture. This arrangement should also economize on the 19 seconds spent in idle table travel.

In the above example 172 seconds was the average cutting time per component. Had that alone been attacked there could not have been much saving. It was only about half the floor to floor time and was not susceptible to so much improvement as was actually made by putting into practice the whole of the above suggestions which resulted (including some decrease in cutting time) in a floor to floor time of 140 seconds as compared with 328 seconds, a saving of 188 seconds.

While an observation is being made the faults in method or manner should be noted, but no attempt should be made to correct them immediately. It is tempting to endeavour to do so but there are good reasons for waiting. In the first place any operator is upset to some extent by being watched. Any comment

or criticism may "rattle" him and cause the study to be misleading. Moreover, secret observations on an extensive scale are not practicable. Consequently every observer should proceed openly, quietly, and, if possible, not grimly. If the conditions prove to be so bad that it would be well to defer the observation, let that be decided upon immediately after the preliminary survey is made. The recommendations for improvement should be written and given to the man responsible for carrying them out, with full verbal explanations. Briefly written notes will suffice but they should be in a definite form, as an order. When the operation has been put into a state fit to study in detail the observation will still probably reveal many defects which can then be dealt with suitably after the study is complete. The business must be considered as a whole. Corrections made as an operation proceeds may be patchy in their effect. This is the second good reason for not making them then. A third reason is that deferring the corrections economizes time all round: it minimizes delay in production, enables time study men to get through more work, and is better for foremen.

As already stated, any operator, whether clumsy or not, will, during the course of several repetitions, perform each simple constituent at approximately the ideal rate now and again. This rule does not apply to complex constituents; they should be subdivided as found necessary.

When the performance time of a given constituent varies much for no obvious reason the exaggerated times may safely be ignored when computing a fair time; but care should be taken to make sure that there are no variables out of the operator's control. Regularity comes only from skill, or long practice. A knowledge of the experience and ability possessed by the operator is therefore helpful. However, it is not essential if the analysis and elimination are well done.

Different men observe and record times in various ways. Most prefer a stop watch. Actually a stop watch

has little advantage except for very short and rapid movements. For machine work a speed indicator is desirable, especially for small brass and aluminium parts. But to save frequent repetition each machine should have a label which states the various speeds and feeds it actually can give, so it is only necessary for this ground to be covered once.

Some observers use two watches, one for the overall time and one for constituent times. A split second hand may be used similarly. But when the constituents follow each other rapidly their study has to be carefully planned, some being observed during one and the rest in other cycles. If an operation contains five constituents the first and fourth may be observed during one cycle, the second and fifth during the next, and the third in the succeeding cycle. The spacing is necessary because the times have to be recorded. It would be possible to construct an observer's clock with a roll of paper moving on a drum on which he could make conventional signs to indicate the time each constituent began and ended. Such a device would save much time in those works where rapid operations are regularly and minutely studied.

Before any timing is attempted a programme of what is to be observed should be tabulated. If only the floor to floor time is wanted the matter is quite simple, needing only a decision as to the starting point. When quantities are large enough to pay for more detailed information, but yet not very large, the loading time and the cutting (or other process) time can be taken as well as the whole cycle time. From these the manipulating time can be derived, it being the difference between the last and the sum of the first two. When a still finer analysis is desirable those constituents which are to be examined can be split as desired into smaller ones. As a rule the main divisions of the operation will be obvious from a preliminary survey.

The first example illustrates how to use an ordinary

watch for finding the floor to floor time for each component. This takes no longer than taking the overall time for a number of components and then finding the average.

Operation. Drill 1 hole $\frac{5}{16}$ inch dia., $\frac{1}{2}$ inch deep.
Datum Point. Picking up component.

Starting time . .	2	58	20	Elapsed Time 25 seconds
Finish (1) . .		58	45	
				27 ,,
,, (2) . .		59	12	
				23 ,,
,, (3) . .		59	35	
				37 ,,
,, (4) . .	3	—	12	
				24 ,,
,, (5) . .	3	—	36	
Starting time . .	2	58	20	136 seconds
Total for (5) =		2	16	
Average =	27 seconds each			

This chart can be prepared beforehand ready for filling in the times in due course. The object of subtracting the starting from the finishing time is to check the arithmetic. The sum of the cycle or elapsed times, 136 seconds, must be equal to the whole time, 2 minutes 16 seconds. The elapsed times are filled in after completing the observation.

If the seconds hand be closely watched there is no difficulty in making such observations correct within two seconds for each separate cycle with a very small average error.

Why the sudden increase to 37 seconds for the fourth component? The reason should be noted on the chart. If the cause of the delay be removed the cycle time reduces to 25 seconds, a difference of about 8%.

For finding constituent times the method just explained can be applied, but unless large work is being observed there will be breaks in continuity owing to the time

necessary to record results. If two watches are used one may be run continuously so that the floor to floor times can be taken regularly.

But the most satisfactory observations are those which give a full record of all that happens during the whole period. If the observer's attention is given elsewhere for a while, if a tool breaks, if the operator goes away to have a chat, the record shows it. The constituents must be chosen carefully and flexibly. There must be space left for noting extraordinary occurrences and for varying a constituent to include more or less to suit the circumstances. If the business is rigidly conducted to discover certain facts the results may be useful. With more flexibility much additional and valuable information becomes available. This kind of observation is not worth while unless preliminary surveys have resulted in the general conditions being satisfactory.

The form of chart recommended for making continuous records is shown in the time study sheet (Fig. 3). A heading, which is not shown, gives the following particulars—

Name and Title of Component.
Number and Description of Machine.
Number and Description of Operation.
Observer's name.
Operator's Name and Check Number.
Date of Observation.
Material, Speeds, Feeds, etc.
Particulars of Cutting Tools and any other essentials.

On the left hand is the column for the main constituents. To the right of these are five columns for observing five cycles. It is not desirable to have more than five because an eye must be kept on the constituent column while figures are being written in the others. The sixth and later cycles may be continued on similar sheets. A stop watch is slightly easier to read than the ordinary kind if it has a plain face not obscured with conversion

figures. The plainer and easier to read, the better is the watch for this purpose. There are many things to observe simultaneously: the operator and his work, the watch, and the record form to see that figures are entered in the correct space. With practice it is not difficult to record in this way unless the chosen constituents take less than

TIME STUDY. SHEET 1.

START: Drop after P/O — CYCLES.

CONSTITUENTS	1	2	3	4	5
STARTING TIME	0·00				
A Feed to stop	05	55	3 14	5·12	6·06
Manipulation		65	16		
B Turn	17	05	25 29 gauge	28	
Man	19	07	4 20 Reset tool		
C Screw	24	1·12	25	35	25
Man		15	4·47 gauge	37	27
D Form	31	20	62	42	34
Man	34	23		44	
E Part off	40	31	5·02	51	43
Man	47	1·35	08	58	51
		2·43 [illegible] 3·09 Trim end			

FIG. 3. TIME STUDY OF CAPSTAN OPERATION

about two seconds. Since the watch is only read to the nearest second it is not to be expected that the records will be quite uniform, even if the motions were made at a constant speed. For instance, if a constituent occupied always 4·5 seconds it is probable that the observer would sometimes write 4 and sometimes 5 seconds as the time. It is probable, in fact, that he would occasionally write 3 or 6 for, in a swift business like this, there are bound to be occasional misjudgments. But the average will not be far out.

The small columns are for entering the observed times

in minutes and seconds. Space is left for notes on occurrences out of the expected routine. For convenient reference the constituents in Fig. 3 have been marked A.B.C., etc. The cycles are numbered.

The Time Study Sheets shown in Figs. 3 to 6 relate to a capstan operation the constituents being as described therein.

It is convenient to have a board on which the forms are clipped in such a way that they may be quickly turned

	CYCLES.				SHEET 2
CONSTITUENTS	6	7	8	9	10
STARTING TIME					
A Feed to stop.	6 56	54	8 34	24	10·16
Manipulation	59			26	
B Turn.	7 07	2·06	49	37	28
Man.	13 gauge		52	39	
C Screw	21	13	57	44	37
Man	23				41
D Form.	29	22	9·04	50	45
Man.	34		·07		
E Part off.	37	28	11	60	56
Man.	40 [illegible]		18	10·10	03

FIG. 4. TIME STUDY OF CAPSTAN OPERATION

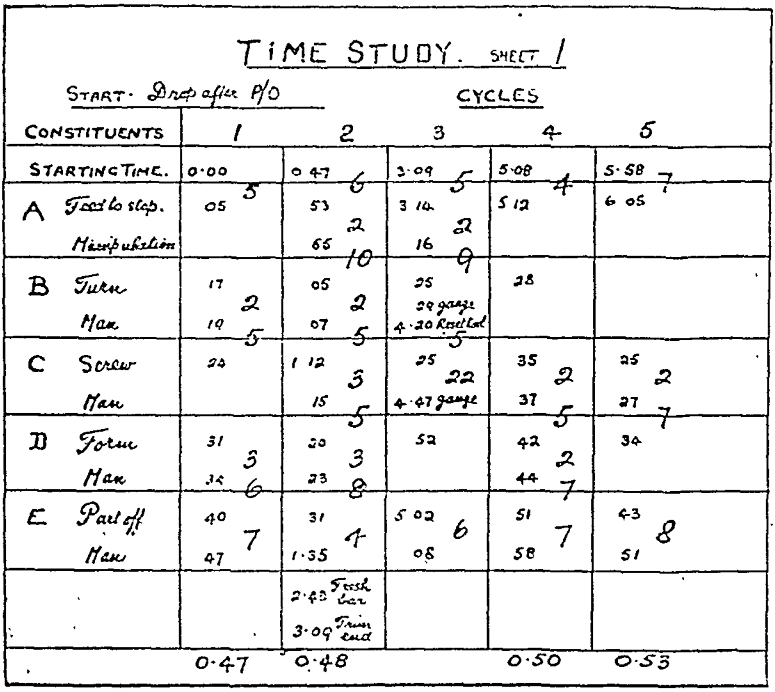
over to make the continuation sheets accessible. The stop watch should be secured to the board in the right-hand top corner, where it can be controlled with the left hand. The starting point having been settled and noted, and the names of the constituents written in, a start can be made.

"Feed to Stop," or A, is the first constituent. It starts at zero and finishes at 0 minutes 05 seconds. The next entry is 17 seconds corresponding with the finish of constituent B. Similarly C ends at 0 minutes 24 seconds. But there is the intermediate entry of 19 seconds. This is the time shown by the watch when the indexing and

sliding of the turret was ended preparatory to screwing.

Since the production is continuous during the whole observation, the end of one motion occurs at the same instant as the next one starts, but it is necessary to think of and record either all the ending or all the beginning times. It does not matter which, but they must not be confused.

The turning B ended at 17 and the manipulation at 19 seconds. Hence the manipulating time is the difference,



TIME STUDY. SHEET 1

START · Drop after P/O — CYCLES

CONSTITUENTS	1	2	3	4	5
STARTING TIME.	0·00	0 47 6	3·09 5	5·08 4	5·58 7
A Feed to stop. Manipulation	05 5	53 2 66 10	3 14 2 16 9	5 12	6 05
B Turn Man	17 2 19 5	05 2 07 5	25 29 gauge 4·20 Reset tool 5	28	
C Screw Man	24	1 12 3 15 5	25 22 4·47 gauge	35 2 37 5	25 2 27 7
D Form Man	31 3 34 6	20 3 23 8	52	42 2 44 7	34
E Part off Man	40 7 47	31 4 1·35	5 02 6 08	51 7 58	43 8 51
		2·43 Feed bar 3·09 Turn end			
	0·47	0·48		0·50	0·53

FIG. 5. TIME STUDY SHEET EXTENDED

or two seconds. Similarly, with D and E the manipulation times are recorded *under* the figures which belong to the principal part of the constituent and in the space *above* the constituent for which they make ready. There is a reason for situating them thus: if they were placed in the space below, just over the constituent which they anticipate, the last manipulation in the cycle at E should

logically be transferred to the head of the second cycle. This would occur in each case. Therefore the last movement of cycle 10, Fig. 4, being transferred to cycle 11, which was not recorded, could very easily be forgotten. It is very important to have the starting and real finishing times correct because they provide a means of checking

	CYCLES. SHEET 2				
CONSTITUENTS	6	7	8	9	10
STARTING TIME	6·51	7·49		9·18	10·10
A Feed to stop. Manipulation	5 6·56 3 59 8	5 54	8·34	6 24 2 26 11	6 10·16
B Turn. Man.	7·07 6 13 gauge	8·06	49 3 52 5	37 2 39 5	28
C Screw. Man	21 2 23 6	13	57	44	37 4 41 4
D Form. Man.	29	22	9·04 3 07 4	50	45
E Part off. Man.	37 49 Rested	28	11 7 18	60 10 10·10	56 7 03
	0·58			0·52	0·53

FIG. 6. TIME STUDY SHEET EXTENDED

the others. That, too, is a good reason for always recording finishing and not starting times of constituents.

At cycle 3 the constituent B did not follow the usual course. Gauging showed tool adjustment to be necessary and extra time was taken. Details were not recorded during the first part of the fifth cycle. E for the next component contains the word *Rested*, signifying that the operator took a short rest.

The next step after observing 10 cycles, is to derive from the record the constituent times and to fill up the gaps as considered reasonable and necessary.

The extended time study sheets, Figs. 5 and 6, indicate how this may be done. The extensions may be on the original sheets in practice. One cycle starts immediately

the previous one ends. Hence a finishing time can be carried, as shown, to the starting times of the next cycle.

Of course the watch could have been reset so that each cycle began at zero, but about one or two seconds would be lost each time, and the amount is uncertain. Moreover, the observer would tend to follow the times of the first cycle; he could not avoid being influenced by them.

TIME STUDY SUMMARY.

Constituent		Cycles. 1	2	3	4	5	6	7	8	0	10	Total	No. obs'd	Average
A	Feed	5	6	5	4	7	5	5		6	6	49	9	5.44
	Man	2	2	2			3			2	2	13	6	2.20
B	Turn	10	10	9			8	10		11		58	6	9.67
	Man	2	2					2	3	2		11	5	2.20
C	Stop	5	5	5					5	5		25	5	5.00
	Man		3		2	2	2				4	13	5	2.6
D	Form		5		5	7	6				4	27	5	5.40
	Man	3	3	2	2	2			3			16	6	2.67
E	[illegible]	6	8	6	7	7			4			38	6	6.33
	Man	7	4X	6	7	6			7	10X	7	42	6	7.00

Average Cycle Time 43.51

FIG. 7. TIME STUDY SUMMARY SHEET

The last movement of the seventh cycle was not recorded, consequently it cannot be entered at the start of cycle 8.

By subtracting the starting from the finishing time for each cycle the FFT is ascertained. For cycle 1 it is 47 seconds. For cycle 2, 4, 5, 6, 9, and 10 it is 48, 50, 53, 58, 52 and 53 seconds respectively.

From "Start" to "Feed to Stop" took 5 seconds, and that amount is entered as shown in cycle 1. In cycle 2 the same business took 6 seconds because it started at 0 minutes 47 seconds and ended at 0 minutes 53 seconds. The records show, too, that manipulating the turret ended at 0 minutes 55 seconds and thus consumed 2 seconds. Turning is entered as finished at 1 minute

05 seconds, and therefore occupied 10 seconds. And in the same way all the other figures which can be directly derived from the first records have been entered in the extended sheets.

The next step is to fill in, according to judgment, times which may safely be surmised if it appear that the direct records are inadequate. In the Summary Sheet (Fig. 7) the constituent times are tabulated from the extensions. An examination of the record shows that manipulation before turning and the actual cutting time were recorded distinctly only four times. But the combined times were observed also in cycles 1, 4, 7, 8 and 10, the amounts being 12, 11, 16, 12, 15 and 12 seconds respectively. It is safe to assume from inspection of the other figures that 12 seconds is a reasonable total, 2 seconds being spent in manipulation, and these have been inserted, as shown, for cycles 1 and 7. Such derived figures have been underlined in Fig. 7. Manipulation B was observed five times but included gauging in cycle 6. From inspection, again, it is evident that 2 seconds as added to cycle 7 is reasonable. Similarly with the other interpolated figures, what appears to be level with the general practice is accepted and other figures ignored until at least five correct results may be assumed to have been obtained for each constituent. Constituent E, cycles 2 and 9, has manipulating times which are doubtful and are therefore discarded.

The average time for each constituent is ascertained by adding the figures from left to right and dividing by the number of observations. The total of the averages gives the cycle time. It does not include allowances for gauging, inserting fresh bars, or for attention to tools. The manner of dealing with these will be considered in a later chapter.

"Feeding to Stop" is equivalent to the more general term "Load" and took 5·44 seconds. Cutting time was distributed thus—

Turning	9·67 seconds
Screwing	5·0 ,,
Forming	5·40 ,,
Parting off	6·33 ,,
Total	26·40 seconds
Machine manipulation . .	16·67 seconds
Total cycle time . . .	48·51 ,,

If the separate cycles which contain no extras are averaged the result is 51·5 seconds. And if the average were taken as a tenth of the whole observed time for the 10 complete cycles it would be—

$$\frac{11 \text{ minutes } 3 \text{ seconds}}{10} = 66{\cdot}3 \text{ seconds.}$$

This, it is evident, would be misleading; and it must be so because it contains extras which normally should be separately allowed for in fixing a basic time. There is no objection to the extras provided their extent is known and it is certain that they are normal as regards the rest of the work. But if they are already present it would not be just to include a further allowance for them in the basic time. It is safest to eliminate them. Then the allowances proper for this class of work, as determined by numerous observations, can be given fairly.

Some indication of gauging, bar feeding and tool adjustments can be gleaned from the record in Fig. 3. Nothing very definite, however, can be affirmed without much more evidence. At B.3 the turned diameter was gauged and the process took 4 seconds. At B.6 it took 6 seconds but included manipulation. Since this manipulation usually occupied 2 seconds the gauging again may be assumed to have taken 4 seconds. Similarly at C.3 gauging the thread plus manipulation took 22 seconds Manipulation being as before the thread gauging may be assumed to have taken 20 seconds. Inserting a fresh bar is recorded after E.2 and took 2 minutes 8 seconds, while facing the end ready to start afresh occupied from 2 minutes 43 seconds to 3 minutes 9 seconds, or 26 seconds,

These times appear to be excessive and could not be accepted as normal without more details and further observation. In the same way the tool resetting record is inadequate. But it will be evident that this method of recording can be made to yield very detailed and complete information according to the skill of the observer and as required. Naturally, when once a sufficient amount of data has been collected it will not be necessary to abstract more from the observation records; the work of time studying will generally end with the tabulated results as shown in Fig. 5.

Particulars of the r.p.m. and rate of feed should be taken before the time observation is commenced to ensure that they are suitable and as desired. Many believe that speeds and feeds should be controlled by foremen or rate fixers. There is not much alternative in some kinds of production, but on repetition work it always pays for them to be specified in the manner which will be explained in Chapter X.

Production operations involve time spent in the following ways—

(*a*) Preparation, that is obtaining instructions, drawings, tools, gauges, etc.

(*b*) Recording. This includes booking time against the job (by clocking on and off or otherwise) and checking quantities as the work proceeds.

(*c*) Getting materials placed ready to pick up for operating upon them, and placing them when finished ready to be taken elsewhere. This sometimes involves a considerable amount of transport and handling which ought to be separated from direct production.

(*d*) Setting up machines ready for production; getting the inspector's approval of the work done on sample components; cleaning machines (this refers to occasional partial cleaning rather than the weekly clean down).

(*e*) Loading and unloading, or setting and securing the work in position for operating upon it and removing it when finished.
(*f*) The effective work, such as assembling, cutting, painting, and so on.
(*g*) Manipulating the machine and tools for (*f*).
(*h*) Resharpening and resetting tools.
(*i*) Gauging.
(*j*) Delays due to various causes, and fatigue.

These are not invariably allowed for in the same way. The chosen method depends on whether the production is—

(1) Non-repetitive as in general engineering and tool-room work.
(2) Repetitive but in small quantities.
(3) Continuous or in very large quantities.

For (1) the items (*a*), (*b*) and (*d*) may be classed together. Often (*c*) is also included but it is better to separate it if materials have to be searched for or the stores service is poor. The average actual times under ordinary conditions for these will be given later. As examples, the sum of (*a*), (*b*) and (*d*) averages 15 minutes for the simplest operations such as shaping a small part which can easily be held in a vice; or drilling one or two sizes of holes on a sensitive drilling machine; or straightforward fitting or assembling. An actual time of 20 minutes suffices for much other light simple work. If gears have to be calculated and set, a further 15 minutes is needed unless the calculation is for a compound train of unusual ratio, when 30 minutes extra will be needed.

If bolts and clamps have to be sorted out an allowance in accordance with the shop conditions must be made—a common figure is 30 minutes. Heavy work or that which requires the improvisation of special tackle must also be judged by the circumstances. There may be considerable uncertainty beforehand and in that event the rate fixer usually has to arrange the price after the work is done and not before it is started.

As a matter of fact, in non-repetition work many prices or allowances are not settled until the work is well advanced. This is not so much that a pre-estimate cannot be made as that the rate fixer, having to take the jobs in rotation, frequently has more on hand at once than can receive his immediate attention. One may infer that ratefixing in that case cannot be very efficient. Yet that would hardly be fair. The only just comparison is that between the results from piece-work and from day-work under conditions which are alike in all other respects.

Work which is mass produced is made faster than if it were produced in small quantities with the same plant. A change in quantities is a vital change in conditions. With equally hard working in both cases the labour costs for a given quantity of output will be different, and this fact will be reflected in the piece-work prices. But this is not evidence that the ratefixing in one case is superior to that in the other.

And because a rate fixer is not always able to price a job at the start there is no reason why he should not be fair. A rate fixer can deal efficiently with from 80 to 100 men engaged in general production when very little of it is repetitive. There are occasions every week when two or three rate fixers would be unable to keep pace with the requests for contracts arising from among such numbers, yet the services of another rate fixer would not be justified, taking the week as a whole. Consequently the requests have to be considered, and the piece-work contract tickets made out, in the order which seems best to the rate fixer.

The only danger of making contracts late is that the man may slack with the hope of getting more than a fair price, or that the rate fixer may be unjust the other way.

When the work is repetitive in small batches items (*a*), (*b*) and (*d*) occur but once for each batch. The recording (*b*) is done by the operator but (*a*) and (*d*) are often done by a setter, while a labourer, who may be assisted by the operator, attends to item (*c*).

In that case these items do not usually rank as direct production costs and they are not included in the operation. Sometimes setting is put on a piece-work basis. The difficulty lies in the fact that the work cannot always be clearly defined. The setter's work is not finished when sample components have been passed by the inspector: he has to maintain the correct adjustments during the whole production; that is, he attends to item (*h*). To change a set-up from component A to suit component B may require a complete stripping from the machine of all the tools and replacement by entirely different ones, whereas the change over from C to B may involve only trifling adjustments.

It is essential for any piece-work contract that the work to be done shall be clearly defined on the contract ticket. If less work is done the contract is either void or payment may be made for that part which was properly completed. Similarly extra work has to be paid for, either by revising the contract or by issuing a supplementary ticket.

In fact a rate fixer often has to issue piece-work tickets for supplementary work. The material may be more difficult to work than usual or was expected; some additional work may be found necessary owing, perhaps, to a faulty drawing, or to the operations not following the proper sequence. There are many possible reasons. And if the contract notes have already been dispatched, as previously described, it is better to issue a supplementary ticket than to withdraw and replace them.

The rate fixer also has to issue day-work tickets for those men who are not continuously on day-work. Obviously if a man does piece-work and day-work alternately he could, if there were not careful control, overcharge day-work to his own advantage. To prevent this from happening the rate fixer has to issue a ticket similar to that used for piece-work (it is often of a different colour to facilitate separation), defining the work but making no

contract. Such tickets are controlled, as regards time booking, etc., exactly as for piece-work, and so prevent dishonesty.

In any sound piece-work system idle time should be paid for through day-work tickets. By *idle time* is meant those periods during which an operator is prevented from working by reasons out of his control. It does not often apply to long periods, for an operator should be released and passed out of the works if it is known that he must be idle for, say, several hours. There can be no rule about this; each case must be judged according to circumstances.

But to insist on having operators paid for the time they waste while waiting for a foreman, or a tool, or for materials, has the advantage of showing at the end of each week, when accounts are made up, how much defective management has cost. In some works and in some trades such idle time is not recognized and is not paid for.

The responsibility for day-work tickets for idle time, or any other purpose, is shared by the foreman with the rate fixer, they issuing them jointly. And since day-work time is only allowed to be booked from the time the ticket is issued, the foreman has warning that either he must find the operator work immediately or have his idle time account charged.

On continuous production (*a*) and (*d*) occur infrequently and any allowances for (*b*) and (*c*) are usually included with the fatigue time. Except when there are many changes in the design of components a rate fixer can attend to about 1,000 men engaged in mass or continuous production. A great deal of his work consists of issuing supplementary or special day-work tickets as just described.

CHAPTER III

DRILLING AND TAPPING

DRILLING is a suitable process to study early because of its simplicity. Once the method of constituents is grasped for any process its application to others is comparatively easy. There are men who seem to know intuitively how long an operation will take when they have examined a component for a few seconds. This is a useful gift to possess and can be developed by practice. The method now to be explained is more laborious. It is also far more certain and can be applied to give accurate results for types of production outside previous experience.

The simplest type of repetition drilling is that widely used in the light castings trade where the positions of the holes to be drilled are determined by dimples in the castings. This practice saves jig making and the jig loading time is eliminated. It has another advantage: the holes will be well placed in relation to the bosses or lugs in the castings, whether shrinkage varies or not, whereas jig drilled holes will not be spaced with this flexibility of position. Drop forgings are often treated similarly. But this method is unsuitable unless either large clearances are permissible or the spacing of the holes in relation to each other is not important.

Although no jig is used, the lifting of the component on to the machine table and the reverse motion may still be termed "loading." Suitable times to allow are shown in Table I, Class 1. The times stated will in all cases be the actual times which the constituent will take on the average. It is important to note this for, in the piece-work system in which time prices are given, they are generally called time allowances and these include a percentage over the actual time.

In the table there are columns for light, medium and

heavy components. A light component is here supposed to weigh not more than about 2 lbs., a medium component up to 10 lbs. and anything over that is heavy. Size must also be considered, because a large article, although light, perhaps, is unwieldy and takes longer to manipulate. The extra time to allow for unwieldy components is given in the right hand column.

Obviously it cannot be definitely stated that loading a given casting will take 10 seconds. It may take only 8 or it may require 13 seconds. One is not compelled to adhere rigidly to the table. Yet the error (if any) by so doing will be trivial. To decide whether 7 or 9 seconds should be allowed may require a long time whereas it is usually easy to settle whether the work is unwieldy or not and its approximate weight. The table gives definite guidance; it gives something stable as a basis, yet it can be modified as desired.

Exchanging drills in an ordinary key chuck requires 30 seconds. So does the exchange of small taper shank drills when the conditions are satisfactory, which they often are not. The 30 seconds includes the time for stopping and re-starting the machine.

The time to allow for lowering a drill into a jig bush or a dimple (including moving the work into position, which is done simultaneously), and releasing the lever for the drill to rise is 2 seconds on light and medium work. If the holes are widely spaced—say over a foot apart—allow 3 seconds. It is seldom necessary to allow more in sensitive drilling, but 5 seconds may be necessary in special cases.

When jigs are used loading time varies approximately as shown in Table I. Loading is understood to include cleaning the jig and the machine table besides unloading. No wielding allowance is required unless the components are of such a length or size, apart from their weight, that extra time is necessary to manipulate them and the jig fastenings.

TABLE I

SENSITIVE DRILLING. LOADING TIMES

	Light	Medium	Heavy	Wielding Allowance
Class 1 . . .	5	10	15	5
Class 2 . . .	15	25	40	10
Class 3 . . .	25	40	60	20

In Class 1 are included jigs of the nut-cracker type and others in which the location is easy, the clamping almost instantaneous, and there is little or no cleaning. Well designed nut-cracker jigs locate and clamp the component with the closing of the handles. Examples in the same class are drilling split pin holes in rods when the rod is located in a vee block and held against an end stop by hand pressure, and jigs in which the component can be dropped or inserted blindly, the clamping being effected by a cam device in one short movement.

The jigs in Class 2 have straightforward location and clamping devices which can be operated with not more than two short movements. Most open or bridge type jigs are in Class 2 unless a spanner or loose key has to be used.

When location is compound, i.e. there is a primary location as by a spigot and a secondary positioning by, for instance, an equalizing device operating on a lug, the times for Class 3 usually apply. Most box jigs belong to Class 3.

The times given may safely be used for estimating yet without settling exactly what the details of a jig will be like. Rate fixers have the advantage of being able to see the jigs in use. But if the loading times exceed those given there is probably something crude about the jig. This often happens where it would not pay to give much time to designing and making the jigs on account of the small number of components for which they will be used.

Nor will the operator acquire dexterity if quantities are small. Hence the times in Table I will generally have to be increased by 50% for first class jigs used for batches of less than 50 and by 100% if, in addition, the jigs are second rate.

Turning a jig over on to another face can often be ignored as a constituent unless it requires two hands. From 3 to 5 seconds, according to the weight, is then usually sufficient. Very massive jigs need up to 15 seconds for each turn over by hand. If lifting tackle has to be used on account of the weight the time required must be estimated in accordance with the conditions.

On most sensitive drilling machines speed changing is too long a job to be included in the midst of an operation. When the variation can be made from the front of a machine by working a lever, or pressing a push button, 3 seconds is a fair time for each change. Again it must be remembered that a return generally has to be made before the cycle is complete. Generally a multi-spindle machine is used when a range of speeds is necessary for one operation.

Higher cutting speeds than those indicated in Table II are sometimes successful. It is unwise to take higher speeds as a basis. What really matters is the rate of penetration, and the revolutions per minute is only one of the factors which determine that.

The speeds given in the tables will be referred to as the ideal speeds. Ideal speeds are seldom attainable; one has

TABLE II

PERIPHERAL CUTTING SPEEDS FOR TWIST DRILLS

	Feet per Minute
Aluminium	350 to 400
Soft brass, copper, manganese bronze	150 to 200
Hard brass, gun metal, phosphor bronze, horn fibre, ebonite	120
Mild steel, malleable cast iron	90
Tough steel	60
Cast iron, slate, marble	50
Steel castings, 50 ton steel	40

to choose the nearest available, as a rule preferring one which is lower unless the next higher is close to the ideal. The rate of penetration does not suffer in proportion because the feed can be slightly coarser at lower speeds. But feeds much in excess of those tabulated will result in overheating, frequent regrinding, and holes out of alignment. There is no economy in forcing.

Most of the sensitive drilling machines in present day use are unsuitable for more than 1,500 r.p.m. Hence the ideal speeds cannot be approached when drilling small holes in brass and aluminium. The difference in output is not very great, however, because deep holes are comparatively few, and with shallow holes manipulation takes far longer than drilling.

TABLE III

DRILLING DATA FOR ALUMINIUM

PERIPHERAL SPEED 400 FT. PER MINUTE

Dia.	R.P.M.	Revs. per Inch	Feed per Rev.	Feed per Minute	Secs. for 1 in. deep
1/16	1,500	330	·003	4·5	14
1/16	10,000	400	·0025	25·0	2·5
3/32	1,500	220	·0045	6·8	9
3/32	10,000	250	·004	40·0	1·5
1/8	1,500	166	·006	9·0	7
1/8	10,000	200	·005	50·0	1·5
5/32	1,500	140	·007	10·5	6
5/32	8,000	166	·006	48·0	1·5
3/16	1,500	125	·008	12·0	5
3/16	6,000	140	·007	42·0	1·5
7/32	1,500	110	·009	13·5	4·5
7/32	4,900	125	·008	39·0	1·5
1/4	1,500	100	·010	15·0	4
1/4	4,000	112	·009	36·0	2
5/16	1,500	90	·011	16·5	4
5/16	3,000	100	·010	30·0	2
3/8	1,500	66	·012	18·0	3·5
3/8	2,400	90	·011	26·0	2·5
7/16	1,500	66	·013	19·5	3
7/16	2,000	80	·0125	25·0	2·5
1	1,500	72	·014	21·0	3
1¼	1,200	64	·0155	19·0	3·5
1½	1,000	60	·017	17·0	3·5
2	750	50	·020	15·0	4

TABLE V

DATA FOR DRILLING HARD BRASS, HORN FIBRE, PHOS. BRONZE, GUN METAL, EBONITE

PERIPHERAL SPEED 120 FT. PER MINUTE

Dia.	R.P.M.	Revs. per Inch	Feed per Rev.	Feed per Minute	Secs. for 1 in. deep
$\frac{1}{16}$	1,500	500	·002	3·0	20
$\frac{1}{16}$	7,300	600	·0016	11·8	6
$\frac{3}{32}$	1,500	330	·003	4·5	14
$\frac{3}{32}$	4,900	420	·0024	11·8	6
$\frac{1}{8}$	1,500	250	·004	6·0	10
$\frac{1}{8}$	3,600	300	·0033	12·0	5
$\frac{3}{16}$	1,500	200	·005	7·5	8
$\frac{3}{16}$	2,400	220	·0045	10·8	6
$\frac{1}{4}$	1,500	176	·0057	8·5	8
$\frac{1}{4}$	1,800	176	·0057	10·2	6
$\frac{5}{16}$	1,500	166	·006	9·0	7
$\frac{3}{8}$	1,200	154	·0065	7·8	8
$\frac{1}{2}$	916	140	·007	6·4	10
$\frac{5}{8}$	733	125	·008	5·8	11
$\frac{3}{4}$	611	112	·009	5·5	11
1	458	90	·011	5·0	12
$1\frac{1}{4}$	366	84	·012	4·3	14
$1\frac{1}{2}$	305	75	·0135	4·1	15
2	229	60	·017	3·9	16

TABLE VIII

Drilling Table for Medium Cast Iron

Peripheral Speed 50 ft. per Minute

Dia.	R.P.M.	Revs. per Inch	Feed per Rev.	Feed per Minute	Secs. for 1 in. deep
$\frac{1}{16}$	1,500	400	·0025	3·7	16
$\frac{1}{16}$	3,000	500	·002	6·0	10
$\frac{3}{32}$	1,500	270	·0037	5·5	11
$\frac{3}{32}$	2,000	284	·0035	7·0	9
$\frac{1}{8}$	1,500	220	·0045	6·8	10
$\frac{3}{16}$	1,000	166	·006	6·0	10
$\frac{1}{4}$	764	142	·007	5·5	11
$\frac{5}{16}$	611	125	·008	4·9	12
$\frac{3}{8}$	509	112	·009	4·6	13
$\frac{1}{2}$	382	100	·010	3·8	16
$\frac{5}{8}$	306	90	·011	3·4	18
$\frac{3}{4}$	254	80	·0125	3·2	19
1	191	72	·014	2·7	22
$1\frac{1}{4}$	153	64	·0155	2·4	25
$1\frac{1}{2}$	127	60	·017	2·2	28
2	95	50	·020	1·9	32

TABLE IX

Data for Drilling 60-ton Steel

Peripheral Speed 40 ft. per Minute

Dia.	R.P.M.	Revs. per Inch	Feed per Rev.	Feed per Inch	Secs. for 1 in. deep
$\frac{1}{16}$	1,500	830	·0012	1·8	34
$\frac{1}{16}$	2,440	1,000	·001	2·4	25
$\frac{3}{32}$	1,600	670	·0015	2·4	25
$\frac{1}{8}$	1,220	500	·002	2·4	25
$\frac{3}{16}$	814	330	·003	2·5	24
$\frac{1}{4}$	611	250	·004	2·4	25
$\frac{5}{16}$	489	220	·0045	2·2	28
$\frac{3}{8}$	407	200	·005	2·0	30
$\frac{1}{2}$	306	166	·006	1·8	34
$\frac{5}{8}$	244	142	·007	1·7	35
$\frac{3}{4}$	204	125	·008	1·6	38
1	153	112	·009	1·4	43
$1\frac{1}{4}$	122	100	·010	1·2	50
$1\frac{1}{2}$	102	90	·011	1·1	55
2	76	84	·012	0·9	67

Since 1,500 r.p.m. is a common workshop maximum the r.p.m. are given for that as well as the correct figure to suit the peripheral speed. The highest r.p.m. in the tables is 10,000. A few machines will exceed this but it is not worth troubling about. There is less drill breakage at the high speeds, undoubtedly. Some of this saving is due to the excellent balance and order in which the quick revolution machines must be maintained.

The next two columns need no comment. What is important is the rate of penetration as shown in columns 5 and 6. Much faster rates are given in many published tables which, however, do not state how long the drills will maintain them. The rates given here are based on drills not requiring regrinding until they have done half an hour's cutting. Perhaps it will be as well to emphasize that cutting time is sure to be far less than floor to floor time. Very slight differences in drill grinding affect the life between regrindings substantially.

In practice 30 minutes' working life is a satisfactory basis. It should be exceeded where holes are shallow and the drill is used intermittently. On the other hand a drill can be forced 30% faster and fail in a few minutes. For multiple spindle work the individual drills must have a fairly easy time to permit a long life. This is obtainable by reducing speeds a little and feeds considerably.

Although the last column states the time in seconds for drilling a depth of one inch, some qualification is necessary for drills under $\frac{3}{8}$ inch diameter: a hole whose depth exceeds three times the diameter is to be considered a deep hole, and it is advisable to reckon on having to withdraw the drill to clear away swarf; hence for, say, a $\frac{1}{8}$ inch diameter drill the time given in the table would be inadequate as it stands. Most holes do not exceed three diameters in depth, consequently the tabulated figures generally apply.

It is to be understood that the speeds and feeds tabulated are for high speed drills flooded with suds (with

the usual exceptions, namely, cast iron, fibre, some kinds of brass, slate, etc.), though at the usual attainable peripheral speeds for small drills carbon steel is just as good.

The two-lip twist drill will not drill deep holes straight. Three-lip drills used for straightening previously drilled holes should run at the speeds given in the preceding tables. The feeds may be doubled if the amount to remove is about $\frac{1}{16}$ inch from the diameter, otherwise use the feeds as listed.

For most purposes reamers may be run at half drilling speed and twice the feed per revolution. Hence reaming a hole takes just about the same time as drilling it; not quite, for the drill has farther to travel than an end cutting reamer because of its point. A hole drilled through a flat (i.e. not dimpled) surface has to penetrate a distance of about one-fourth the diameter of the drill in addition to the nominal depth of the hole. Three-flute drills and reamers must be allowed to penetrate about $\frac{1}{8}$ inch farther than the nominal depth. Mild steel is often reamed at drilling speed. The reamers last well at the usual reaming feeds when well flooded with suds.

The amount of material left for reaming should be small. Less than $\frac{1}{64}$ inch in diameter is sufficient for $\frac{3}{8}$ inch and smaller drills where number and letter sizes are available. From $\frac{7}{16}$ inch to $\frac{3}{4}$ inch diameter an allowance of $\frac{1}{64}$ inch suffices. For larger sizes $\frac{1}{32}$ inch is safer if the reamed surface is to be free from blemishes. Unless a three-lip drill precedes the reamer, actually less than $\frac{1}{32}$ inch will have to be reamed out because the drills are sure to cut a trifle large.

Exchanging slip bushes in a jig frequently takes from 20 to 30 seconds when the common method of securing them with large headed screws is used. The exchange has to be made twice, i.e. from drilling to reaming size and back again for the next component, making 50 seconds, say, for each hole. For intensive production quicker and easier bush fastenings are used. A bush should drop in place freely, tightening up in position only for the last $\frac{3}{8}$ inch or so.

Taper fits are not satisfactory because of dirt, but an almost imperceptible shouldering and a ball end for leading the bush in are commonly used. The same idea is applicable to plug gauges.

Racks suitably placed for hanging drills and reamers ready to be taken in turn also save much time. In fact, when the racks are made so that the tools remain in their slip bushes the whole double exchange in a quick change chuck, i.e. drill to reamer and reamer to drill, including the bushes, can be made in 30 seconds if the bushes are of the easy insertion type. This is a saving of 30 seconds per hole, for the 50 seconds just given did not include exchanging tools.

If possible, operations such as tapping, counterboring, etc., should be arranged so as to avoid the use of slip bushes. Sometimes the bush plate can be entirely removed, or be hinged for swinging clear. In other cases, when the quantities to be made justify the expense, a stand is made to hold the component if its own base will not support it satisfactorily. Either way is quicker than using slip bushes.

The best radial drilling machines are astonishingly quick and easy to handle. When holes of the same size are not more than 3 or 4 inches apart a good operator on intensive production takes not more than 2 seconds per hole to raise and lower the drill and move the spindle into position. By intensive production is meant production at the speeds attained in first class work where the quantities made are large and the operators work confidently as fast as they can. The above figure—2 seconds—is for light work. Heavier machines naturally take longer to manipulate, but 5 seconds per hole is sufficient as a rule. These times must be about doubled if the holes are far apart or are situated awkwardly. Such cases have to be considered as they arise and judgment used. See also Chapter X.

Clamping the radial arm on a pillar takes from 5 to 10

seconds according to the size of the machine. On modern machines speed changing should take no longer than 3 seconds. On an ancient machine it may take anything up to 2 minutes per change.

Spot facing and counterboring speeds should be the same as for drills of corresponding diameters but the penetration rates should be halved. It is not worth while forcing such tools, for the cutting time is always small.

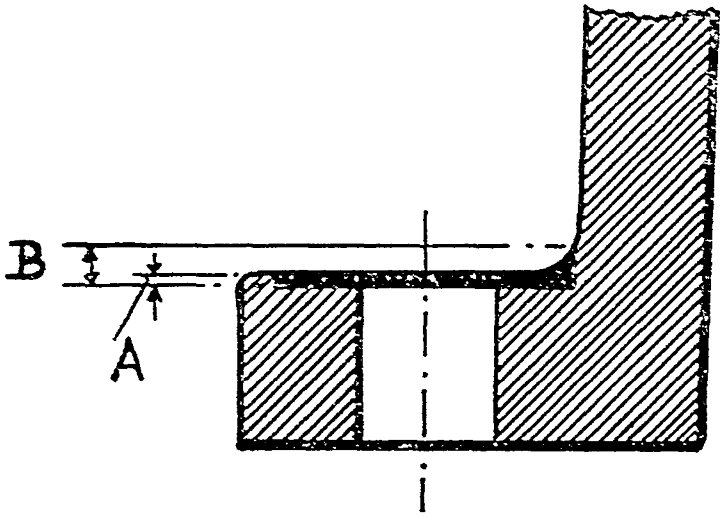


FIG. 8. SPOT FACING

The amount to remove by spot facing is often more than the nominal amount owing to various irregularities. One of the worst troubles (it should be eradicated if possible) is that shown in Fig. 8. Here the nominal amount to remove is A but the cutting commences earlier and the time is governed by B. Again, there should be a dwell at the end of the cut to "feel" the stop and to impart a good finish. This is conveniently allowed for by adding for the time calculation $\frac{1}{16}$ inch to the depth removed. When facings have to be cut to a gauge level milling is far quicker and better than spot facing.

In intensive production countersinking (including burring or frazing) is a rapid operation at which women

excel. When the top diameter of the countersink is not over $\frac{1}{2}$ inch and the holes are not more than 2 inches apart, in light easily handled work, the time per countersink does not exceed 2 seconds, the holes having been previously drilled. If the countersinks are of various sizes and the holes have to be selected 3 seconds each is enough. One or two extra seconds per hole is necessary if the holes are wide apart or manipulation is for any reason not extremely easy. In practice countersunk holes are usually in groups or rows and manipulation presents no difficulty. The above figures apply to all materials, for cutting time scarcely enters into the business. Larger countersinks may be treated as for drilling but allowing $\frac{1}{8}$ inch on the depth for dwelling to obtain the finish. For ordinary (that is, not intensive) production the figures just given must be doubled. In any case no allowance is included for tool changing, or setting, and only very occasional gauging is possible at such speeds.

It may seem unpractical to work out operation times by the use of data of the kind detailed above. So it would be if continual reference had to be made to the tables. The remedy is to learn the facts and how to apply them with due judgment. A little practice enables one to forecast within a few seconds what any floor to floor time should be, reference being made to the tables occasionally for figures which are not already known because infrequently used.

And for many purposes a good deal of simplification is justifiable. Estimating does not take long if the procedure is methodical and averages are used with good judgment.

For example, suppose ten holes are to be drilled in a mild steel component on a two spindle sensitive drilling machine, the holes being of various diameters and depths. It does not follow that the calculation must be laborious. Let the holes be as follows—

2 holes	$\frac{1}{8}$ in. dia.	$\frac{1}{2}$ in. deep
4 holes	$\frac{1}{4}$ in. dia.	$\frac{1}{2}$ in. deep
4 holes	$\frac{5}{16}$ in. deep	$\frac{3}{4}$ in. deep
1 hole	$\frac{3}{8}$ in. dia.	$\frac{3}{4}$ in. deep
1 hole	$\frac{31}{64}$ in. dia.	1 in. deep

The last hole is to be reamed to ½ inch diameter and all depths are to the point of the drill.

The loading constituent will be found in Table I. In this case assume medium Class 2.

The holes are to be drilled from 3 faces, hence the jig must be turned over three times (in some cases twice might do; this must be considered; it depends on the sequence of movements found necessary). There will be sliding of the jig from the first to the second spindle and back again. The necessary work will require the spindles to be raised and lowered at least 15 times, allowing two extra movements for the ⅛ inch diameter holes, which are "deep," being over 3 times the drill diameter. Six tool changes will be necessary, there being 5 drills and 1 reamer used. (Sometimes 5 changes would suffice for the reasons mentioned regarding turning the jig over.) Slip bushes will be exchanged for the reamer.

Since there are only 2 spindles it will be impossible to work at ideal speeds for every drill. Let the reaming be done at drilling speed and use the same spindle for drilling $\frac{5}{16}$ inch, ⅜ and ½ inch diameters, running at 600/700 r.p.m. The other spindle may run at 1,300/1,500 r.p.m. Because of these compromises allow an average penetration rate of 4 inches per minute.

This is a practical rule of great value in such cases. It may be applied equally safely to cast iron components,

Constituent	*Time*
Loading	25
Overturn jig, thrice	0
Slide jig, twice	2
Raise drills, 15 times	30
Change drills, 5 times	25
Reamer and slip-bush change	30
Gauge	4
Drill at 4-in. rate $\frac{8\frac{1}{4} \times 60}{4} =$	124
	240 sec.

(*a*)
$$1 \text{ in.} \times 1\tfrac{1}{2} = 1\tfrac{1}{2}$$
$$\tfrac{3}{4} \times 5 = 3\tfrac{3}{4}$$
$$\tfrac{1}{2} \times 6 = 3$$
$$8\tfrac{1}{4} \text{ in.}$$

the same penetration rate of 4 inches per minute being used, unless the holes are mostly $\frac{1}{2}$ inch diameter or over, or are of one size at which the ideal speed and feed is attainable.

The foregoing considerations will take only a few seconds in practice and the numerical results can be set down as given in the table at the foot of page 59.

The reamer will pass through in half the time taken for drilling, hence the odd half inch at (*a*).

The allowance of 2 seconds for sliding the jig from spindle to spindle is made on the principle that every known constituent must be recorded, however small the time allotted to it. Yet no time is given for overturning the jig. The justification for this is that most of this constituent can be done while the drill spindle is being raised and lowered; moreover the allowance of 2 seconds for each repetition of this movement is somewhat excessive.

The cycle time, 240 seconds, would be attained only in intensive production. It would have to be adjusted in other cases as shown elsewhere. The fatigue allowance with so many changes must be high in any case. See page 71.

Of multi-spindle drilling there are several varieties. Here multi-spindle drilling will mean two or more spindles working together in one head. Gang drilling will mean drilling with separate spindles which may work independently but share one long table.

In the simplest form of multi-spindle drilling there is but one jig station. This is under the spindles, and while the jig is being loaded drilling is stopped. This will be termed class A and is shown at *a* and *b* in Fig. 9. The constituents are the same as in ordinary single spindle work. There are two stations in class B, the next variety, one for loading the jig and one for drilling, as at *c* in Fig. 9. Loading takes place during drilling, hence time is saved. The constituents are—

(1) Either loading or drilling, whichever is the longer.

(2) Raising and lowering the multi-head.
(3) Indexing the jig from one station to the other.

The other varieties are developments of the two just

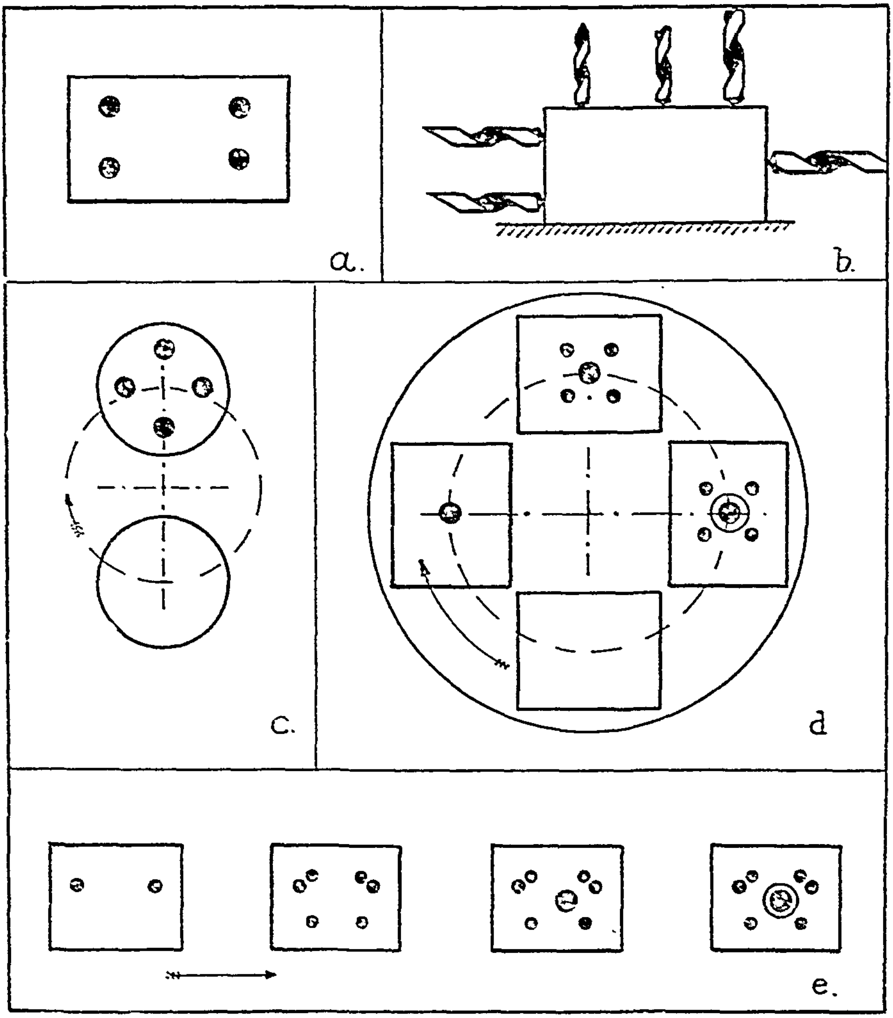


FIG. 9. MULTI-SPINDLE AND GANG DRILLING

mentioned. For example, there may be one station with several multi-heads working, either simultaneously or separately, on different faces of the component (Fig. 9*b*). There may be one loading station at a rotatable indexing

table and several stations for drilling, reaming, or counterboring (Fig. 9*d*). Sometimes two or more components are loaded together. The arrows in *d* and *e*, Fig. 9, indicate the direction of work flow.

The penetration rate for multi-spindle drilling is often about $\frac{1}{2}$ or less of that which would be used for drilling the holes separately. This is partly because the pressure and power required to drill at the ideal rate would compel the use of enormously substantial machines, and the time saved, if any, would not pay for their cost; and partly because in all kinds of multi-spindle work it is necessary to minimize drill grinding. Speeds and feeds must be comparatively low in order that the drills will last during a whole day at least without requiring resharpening. A good average penetration speed for a multi-head is about 2 inches per minute for, say, a dozen $\frac{5}{8}$ drills cutting cast iron, or mild steel. This rate would be trebled for aluminium. But it depends on the power and rigidity and other characteristics of the machines and has to be ascertained in every case.

There is a slight gain by increasing the penetration rate for class A but none for class B if the drilling time is equal to or less than the loading time. For example, in the first case suppose the constituents to be:

Load, etc.	40 sec.
Raise, etc., drill	10 ,,
Drill	30 ,,
Total . . .	80 sec.

Then if the drilling time is reduced to 20 seconds the cycle time is reduced to 70 seconds.

In class B suppose the constituents to be:

Load, etc.	30 sec.
Index	10 ,,
Raise, etc., drill	10 ,,
Total . . .	50 sec.

If the cutting time at none of the stations (it makes no difference how many there are) exceeds 30 seconds there

will be no change in the cycle time by accelerating cutting unless the loading constituent can also be reduced. For this kind of work it is a safe rule to attack always handling times and to be generous with cutting times.

Gang drilling (Fig. 9*e*) is scarcely as rapid as multi-head indexing work because of the time required to slide the jig from spindle to spindle. In other respects it is superior and is to be preferred unless an exceptionally large number of unvarying components will be made. It is better for several reasons—

(1) Instead of one large machine there are several machines (or separate spindles) which can be used for other work without much trouble.

(2) The indexing table on which the jigs are mounted for class B has to be of extreme accuracy and the spacing of the jigs must be precise. Gang work needs less refined tool making.

(3) When a component is modified it may be difficult or impossible to alter the indexing machine or jigs without great expense. With the gang arrangement conversions are, in general, simpler and far less costly.

(4) Any of the main spindles in the gang may carry a multi-head for drilling a group of holes and the speeds and feeds can be suited to the group. When one large multi-head is used only one rate of feed is possible unless extraordinary arrangements are made.

In the simplest form of gang drilling only one jig is used (unless successive jigs are required at stages in the work) and this is passed successively from station to station. (The word *station* is used because there may be a multi-head with several spindles at any station.) When large quantities are being made with power feed machines there is one more station than there are main spindles, and a jig at every station. These are passed along successively, the one from the last station in the line

being brought back to the starting place for loading again. Alternatively, in some cases the jigs may be fixed and the component only passed along. In that case there will be no return.

If only one jig is used the cycle time will be built of the following constituents—

(1) Loading and unloading jig.
(2) The sum of the spindle raising and lowering times at each station.
(3) The sum of the sliding times from station to station (including the return).
(4) The sum of the cutting times at each station.
(5) The sum of any other constituent times at the stations.

The cycle time for any particular case may be forecast from the data already given.

With the gang system, when several jigs are employed, the cycle time may be found by adding together the whole of the handling times, including moving from spindle to spindle and loading, unless the sum is exceeded by the cutting time plus the immediately associated handling time at one spindle. In that case the latter is the cycle time.

An example will make this clear. Suppose the gang consists of four main spindles. It does not matter how they are used, that is any of them may have a multi-head attachment or work simply; they may be drilling, reaming, counterboring or tapping. To find the cycle time it is necessary to know the times for all the handling constituents and the longest cutting time. It is unlikely that the spindles will be equal in this respect.

Station 1—1st spindle. Cutting time	40 sec.
Manipulation	20 ,,
Station 2—2nd spindle. Cutting time	60 ,,
Manipulation	12 ,,
Station 3—3rd spindle. Cutting time	35 ,,
Manipulation	20 ,,
Station 4—4th spindle. Cutting time	25 ,,
Manipulation	10 ,,
Station 5—Manipulation. Unloading, returning jig to Station 1, reloading and manipulation . .	50 ,,

In the table on page 64 each manipulating constituent is related to the spindle below it and includes sliding and fixing the jig in position, lowering the spindle ready to start cutting and setting the power feed working. The total manipulation time amounts to 112 seconds and this is also the cycle time. But if the cutting time at, say, Station 2, were 120 seconds and its related manipulation time were 20 seconds, the cycle time would be 140 seconds. With machines not provided with automatic feed and trip the time would be 272 seconds for the constituents as originally listed.

When the cycle time depends entirely on manipulation time there can be no advantage in reducing cutting times, and in practice the cutting tools should be given easy duties. It is hardly possible to over-emphasize this fact, because so much has been made of high cutting rates.

Suitable peripheral speeds for tapping are shown in Table X.

TABLE X

TAPPING SPEEDS IN FEET PER MINUTE

25 ft.	per minute	for	cast iron
15	,,	,,	mild steel
10	,,	,,	tough steel
60	,,	,,	brass
150	,,	,,	aluminium

With fine threads 30% higher speeds may be used under favourable conditions. The time saved is negligible, except in the case of large taps used on tough materials; it is safer, as a rule, not to exceed the speeds given above, except as indicated in Table XI. This shows suitable r.p.m. for Whitworth taps of various sizes and different materials. It will be noted that no speed higher than 1,500 r.p.m. is given, otherwise the speeds for the smaller taps are slightly in excess of those in the table, and of the

larger ones rather lower. The heavier cuts naturally have to be made slower. If desired, and there is ample lubrication, gas taps can safely cut 30% faster, remembering, of course, that the real and not the nominal diameter of the tap must be used to determine the peripheral speed. When there are fewer than 8 threads per inch, it is advisable to use two taps, one for roughing and one for finishing; hence times will be approximately doubled. Rather more, because of the exchange.

The lead at the point of a tap usually extends over about 4 threads. It is inconvenient to use this as a dimension and practically it may be taken as half the nominal diameter of the tap. That is, if a $\frac{1}{2}$ inch gas thread is to be tapped $\frac{3}{4}$ inch deep the real depth tapped will be—

$$\tfrac{3}{4} + \tfrac{1}{2} \times \tfrac{1}{2} = 1 \text{ inch.}$$

The tapping time depends on the real depth, not the nominal depth in which the full thread exists.

Small holes can be tapped with extraordinary speed under favourable conditions. A skilful operator can easily tap 1,000 blind holes an hour in aluminium up to $\frac{1}{4}$ or $\frac{5}{16}$ inch Whit. on a light radial machine.

As a matter of fact, blind holes can be tapped as rapidly as open ones if they are drilled deep. The depth drilled below the end of the full thread should be $\frac{3}{4}$ the tap diameter. Even then any chips left from drilling must be cleared to make room for the point of the tap.

In its retreat the tap must make as many turns as it required in the advance. The speed of the retreat is often about the same as the advance but is generally faster. A good ratio between the two speeds is 2 : 1 and this will be assumed generally as the basis for time calculations. Collapsible taps are unpopular and in any case need not be specially considered.

If the diameter of a tap is D, the depth of full thread

is L and the number of threads per inch is N, the time the tap will be in the hole is given by—

$$\frac{\frac{3}{2} \times \left(L + \frac{D}{2}\right) \times 60 \times \text{T.P.I.}}{\text{R.p.m.}}$$

For open ended holes add about $\frac{1}{8}$ inch to L to allow for deeper penetration. The factor 3/2 is on the assumption of the 2 : 1 ratio between retreating and advancing speeds. For any other ratio it will need adjustment. If the ratio is 1 : 1 the approximate factor will obviously be 2, or if it is $1\frac{1}{2}$: 1 the factor will be 5/3.

TABLE XI

TAPPING SPEEDS: REVS. PER MINUTE

Dia. of Tap	Aluminium	Brass	Cast Iron	Mild Steel	Tough Steel
	R.P.M.	R.P.M.	R.P.M.	R.P.M.	R.P.M.
$\frac{1}{8}$	1,500	1,500	800	500	300
$\frac{3}{16}$	1,500	1,200	500	330	200
$\frac{1}{4}$	1,500	900	400	240	150
$\frac{3}{8}$	1,500	600	250	150	100
$\frac{1}{2}$	1,100	450	190	115	75
$\frac{5}{8}$	900	350	150	90	60
$\frac{3}{4}$	700	280	120	70	50
1	500	200	90	50	35
$1\frac{1}{4}$	400	150	70	35	25
$1\frac{1}{2}$	300	120	55	25	18

But since handling time forms so large a part of total tapping time the above formula is unsuitable for everyday use, though necessary for special cases. Handling time, including raising and lowering tap (or the equivalent), applying lubricant and occasional gauging should be about 5 seconds for $\frac{1}{4}$ inch diameter taps, 8 seconds for $\frac{1}{2}$ inch, 12 seconds for 1 inch and 15 seconds for $1\frac{1}{2}$ inch diameter taps.

The depth of tapping (full thread), except in the case of gas threads is usually close to 5/4 D for steel, 3/2 D for cast iron or brass and 2 D for aluminium. The following formulae take into account the foregoing and provide a ready means of quickly estimating tapping times. Of course simple straight line formulæ cannot be quite accurate for the whole range. However, they are near enough for most purposes. The only case where there is much divergence from practice is in tapping tough steel. For $1\frac{1}{2}$ inch Whit. the formula time is deficient by about 10 seconds per tap per hole.

TABLE XII

TAPPING TIME

Material	*Time in Seconds*
Aluminium	$10D + 2$
Brass	$16D + 2$
Cast iron	$24D + 2$
Mild steel	$32D + 2$
Tough steel	$48D$

The time in seconds is per tap per hole and the formulae apply quite well for both Whitworth and B.S.F. threads. For gas threads of ordinary proportion between L and D they also apply if the diameter D be the actual, not the nominal diameter.

In these formulae the whole of the manipulation and occasional gauging is allowed for. Separate loading time is not included. Thus, if a component has to be lifted to the table and set down while other motions cease this has to be allowed for in the time.

But small components can often be successively dealt with with one hand while the other manipulates the machine. In that case the formula time requires no addition; indeed, it is often slightly generous.

According to the formula, tapping a hole 1 inch Whit. in cast iron takes $24 \times 1 + 2 = 26$ seconds; tapping a $\frac{1}{4}$ inch Whit. hole in aluminium will take $10 \times \frac{1}{4} + 2 = 4\frac{1}{2}$ seconds, and a $\frac{3}{16}$ Whit. hole in brass $16 \times \frac{3}{16} + 2$

= 5 seconds. It must not be forgotten that holes of abnormal depth must be treated specially. For many commercial threads, especially in light electrical components, $\frac{3}{4}$ of a full thread is adequate. This eases tapping considerably. Whereas the difference between the theoretical root and top diameters of a tap with Whitworth shaped threads is given by

$$\frac{1 \cdot 28 \text{ inch}}{\text{T.P.I.}}$$

it is safe for many purposes to deduct

$$\frac{1 \text{ inch}}{\text{T.P.I.}}$$

from the top diameter for the tapping size.

For example, a 1 inch Whit. Tap has 8 T.P.I. and a root dia.

$$1 - \frac{1 \cdot 28}{8} = 0 \cdot 84 \text{ inch.}$$

The "commercial" formula gives $1 - \frac{1}{8} = 0 \cdot 875$ inch diameter for the tapping size.

Similarly the two tapping diameters for a $\frac{3}{8}$ inch B.S.F. thread are

$$\cdot 375 - \frac{1 \cdot 28}{20} = 0 \cdot 311 \text{ inch}$$

and

$$\cdot 375 - \frac{1}{20} = 0 \cdot 325 \text{ inch.}$$

The "commercial" formula may not be used for highly stressed parts but it is generally desirable to use a drill about ·005 inch larger than the theoretical size even for those. For superfine work undersize machine taps are used and size is got by hand tapping afterwards.

Since the motions for tapping closely resemble those used in drilling there is no need to consider constituent times further, except to mention that when taps are lubricated by applying a lump of tallow the motions take

about 3 seconds for each application. Gauging time is included in the formulae above and should not exceed 1 or 2 seconds per hole, being occasional.

As previously stated the sum of preparation, recording, and setting times is about 15 minutes for simple drilling machines if the tool service is good. For every tool (including jigs) above 3 add another 3 minutes. Unfortunately there is frequently delay between batches which is charged to the job directly when it should be booked as "idle time." Such delays deceive one as to the true operation or setting times and are worst in the jobbing shops. It would pay them to develop swift tool service.

When drills cut at the ideal rates given in Tables III to IX an allowance of 5% on the cutting time of each drill will cover time spent in regrinding or exchanging and replacing in the machine. If operators are allowed spares this allowance may be reduced to $2\frac{1}{2}\%$.

The penetration rate being much slower in the case of multi-spindle drilling the tool attention allowance is far less per drill. As a rule, the operator does not grind his own drills. but has to make the exchanges and length adjustments. An allowance of 5% on the cutting time plus $\frac{1}{2}\%$ for each drill is usually satisfactory. Thus a head with 20 drills taking 80 seconds to penetrate each component would have a tool allowance of $5\% + 20 \times \frac{1}{2}\% = 15\%$. 15% of 80 seconds = 12 seconds (per component).

On the average about 40 minutes a day are spent by an operator in breathing spells and rests which are natural and necessary; another 10 minutes or so has to be allowed for stoppage such as waiting for foreman or inspector and similar delays. Then, in addition to the recording already allowed for, some time is spent in checking and noting quantities done and other particulars. The net result is that to an observed or calculated floor to floor time a "fatigue" allowance of $12\frac{1}{2}\%$ must be added.

The only exceptions are light work, which does not demand continuous attention, when $7\frac{1}{2}\%$ is enough; and work which for any reason is trying, when anything up to 30% will be necessary.

Most simple drilling requires the average allowance of $12\frac{1}{2}\%$; and since, in many cases, cutting time is about half the floor to floor time, the tool allowance of 5% on cutting time may often be taken as $2\frac{1}{2}\%$ of the floor to floor time. Thus 15% on the latter accounts for both fatigue and tools. If due allowance is made for preparation and the other incidentals it is not necessary to add much to the intensive times given for drilling, tapping, etc., for moderate quantities. An extra allowance of 20% should cover what is necessary for batches of between 50 and 100 components. For lots of under 20 this may be increased to 50%. When tool changing is incessant, as in the example on page 59, add up to 15% for extra fatigue. There is considerable mental strain.

In general, if a batch of, for example, 80 components were to be drilled in one operation the first consideration would be the allowance for preparation, recording, and setting up as previously described. A fatigue allowance on these is unnecessary, but 25% must be added if the operator is to earn time and a quarter. If the operator should spoil a few of the components he would receive no extra time for the replacements. But should his foreman, requiring a few components urgently, request the 80 to be machined in two lots—say 20 and 60—he would be entitled to preparation and setting allowances for two batches if the upset justified it.

For simplicity, let the FFT = 100 sec.

20% moderate quantity allowance		$= \dfrac{20}{120}$ sec.
15% fatigue and tool allowance	$= \dfrac{15 \times 120}{100}$	$= \dfrac{18}{138}$ sec.
25% P.W. allowance	$= \dfrac{25 \times 138}{100}$	$= \dfrac{34}{172}$ sec.
P.W. time allowance = 172 sec.		$= 2{\cdot}87$ min.

The constituents under the main heads of loading, handling and cutting having been timed for intensive working, by the foregoing rules, percentages would be added, as given on page 71, to determine the time allowance.

Further examples with detailed working are given in Chapter X.

CHAPTER IV

PLANING, SHAPING, SLOTTING, AND BROACHING

SHAPING and other reciprocating machines waste a large amount of time in the idle or return strokes. The real cutting speed could be, for the forward strokes, as given in Table II. But since the cutting is not continuous the effective speed is far less. It is the effective speed which counts in time calculations. The effective speed in feet per minute is 58480

$$\frac{L}{12} \times \text{number of forward strokes per minute,}$$

where L is the length of the forward stroke in inches.

For example, if a shaping machine makes 30 forward strokes per minute, each 12 inches long, the effective speed is

$$\frac{12}{12} \times 30 = 30 \text{ feet per minute.}$$

Each cutting stroke may take, say, 1·2 seconds, and each return stroke 0·8 seconds. Thus the cutting speed averages 1 foot in 1·2 seconds, or 50 feet per minute. The word "averages" should be noted in this connexion because in most shaping and slotting machines the cutting speed at the centre of the stroke is much greater than at the ends.

It is inconvenient to ascertain for each occasion what the variation may be, so the difficulty is avoided by choosing a rather low average speed. Suitable (average) cutting speeds are shown in Table XIII, page 74.

For modern machines the effective speeds are usually about three-fifths of the cutting speeds, and this ratio will be assumed in the examples; but many slotting machines and some shaping machines work less effectively.

TABLE XIII

CUTTING SPEEDS FOR SHAPING AND SLOTTING MACHINES

Material	*Feet per Minute*
Cast iron	35
Mild steel	60
Tough steel	40
50-ton steel	30
Gun metal, etc.	80
Aluminium	80

In any particular case the capabilities of the machines should be ascertained.

Of course the table speeds can seldom be got exactly. The low speeds given for the brasses and aluminium are about as high as reciprocating machines permit.

If S is the length of stroke in inches
C the cutting speed in feet per minute
E the effective speed in feet per minute

and N the number of strokes per minute

$$E = \frac{3}{5} C \text{ (as a rule)},$$

and
$$N \times \frac{S}{12} = E = \frac{3}{5} C.$$

Hence
$$N = \frac{36C}{5S}$$

If L be the length of the work in the direction of the cut, S is commonly $(L+2)$ inches.

To allow for irregularities in the work, trial cuts and some of the handling, add 1 inch to breadth B. Thus the area swept by the tool will be reckoned as $(L + 2)(B + 1)$ square inches for shaping a surface measuring $L \times B$, L being in the direction of the stroke. About half the 1 inch added to B is to account for handling, this being far better than adding it entirely as a percentage of the cutting time, though, as will be seen, a further amount is thus added.

If F be the feed per stroke in inches the area swept per minute by the tool is

$$NF(L+2) = \frac{36C}{5(L+2)} \times F(L+2).$$

It follows that the time for shaping a surface measuring $L \times B$

$$= \frac{5(L+2)(B+1)}{36CF} \text{ minutes.}$$

This general formula may be simplified to

$$\frac{(L+2)(B+1)}{K}$$

for special cases where K has values to suit the chosen combination of speeds and feeds. Table XIV gives values for K which are in accord with good practice on average machines.

TABLE XIV

VALUES OF CONSTANT K FOR SHAPING

	Roughing	Finishing	Scraping
Cast iron	8	16	40
Mild steel	10	16	—
Tough steel	6	10	—
Brass	20	30	—

For example, shaping a cast-iron face measuring 10 inches × 6 inches will take for the first cut

$$\frac{(10+2) \times (6+1)}{8} = 10{\cdot}5 \text{ minutes.}$$

This, of course, is a bare cutting time. Surfaces at one level but interrupted by a tenon require the 1 inch addition made to each breadth.

The formula will be a safe guide to ordinary working

when taking roughing cuts up to $\frac{3}{16}$ inch deep, finishing cuts $\frac{1}{32}$ inch deep and scraping cuts up to 0·010 inch deep. Feeds per stroke may be as shown below—

TABLE XV

FEEDS FOR SHAPING MACHINES

Material	Roughing	Finishing
Cast iron	$\frac{1}{32}$	$\frac{1}{60}$
Mild steel	$\frac{1}{40}$	$\frac{1}{25}$
Tough steel . . .	$\frac{1}{56}$	$\frac{1}{32}$
Brass	$\frac{1}{30}$	$\frac{1}{20}$

These are a guide only, for no machine will give either the exact speed or feed for all conditions. If the possibilities of the machines are unknown the safe plan will be to use the simple formula for calculating the time. But if speeds and feeds are both known the general formula will give an accurate result (subject to the assumed 3 : 5 ratio).

An allowance of 15% will cover fatigue, tool attention, and the remaining machine manipulation for plain work. If there are ledges to shape at heights within fine limits allow (B+1) inch for the width of the first or datum surface of width B, and similarly for those cut in relation to it. Also, for any secondary surface to be extremely accurately placed, allow two finishing cuts. If there is much fine limit work of this character allow 25% instead of 15% for fatigue, etc. It will be necessary on account of the physical strain in gauging and fine tool setting. If inclined surfaces have to be shaped allow 10 minutes, when the angle has to be measured accurately, for setting the head correctly. For rough work two minutes will suffice each time the head is set over.

When work of a fairly uniform character is done the whole cutting time may be calculated by the simple

formula, using a suitable value of K for the purpose. For instance

$$\frac{(L + 2)(B + 1)}{5}$$

gives the approximate time in minutes for shaping a cast iron surface, taking two cuts as a rule, but occasionally three. In practice the second cut is not always successful as regards both size and finish. Moreover, if the amount of metal to remove is excessive several roughing cuts may be required.

Shaping machines are not much used for intensive production, but operators usually have accumulated a variety of bolts and clamps suitable for their general needs, and can set up quickly. However, frequent changes are exhausting and the preparation and setting allowances should be not less generous than those mentioned on page 41.

The effective speed of modern planing machines usually approaches $\frac{3}{4}$ of the cutting speed. Generally 30 feet per minute effective speed is a satisfactory basis for estimates when it is known that a modern machine is available and exact particulars cannot be obtained. For the older machines 20 feet per minute is more common.

The cutting and effective speeds of planing machines are not constant for all strokes, but there is no need to take this into account except for very short surfaces. Then the definite decrease in speed may conveniently be allowed for by assuming for the purpose of calculation that the surface is longer than it actually measures. Whereas 2 inches is added to the length of the surface to ascertain the suitable stroke for shaping, 10 inches is generally the proper amount for planing machines. But when the surface is less than 24 inches long assume still that a 34 inch stroke will be used. This will compensate sufficiently well on machines of ordinary pro-

portions for the loss in speed. Naturally, it is better to use accurate figures if they are available.

The time in minutes for planing one cut over a surface L inches long (in direction of cut) $\times$ B inches broad with a single tool is given by

$$\frac{(L + 10) \times (B + 2)}{K}$$

where K is a constant to suit the conditions. If the symbols are as previously used,

$$N \times \frac{S}{12} = E = \frac{3}{4} C \text{ (as a rule)}$$

Hence $$N = \frac{9C}{S}$$

Area cut per minute

$$= N \times F \times S = \frac{9C}{S} \times F \times S$$

If, as is often the case,

$$C = 40 \text{ feet per minute}$$

$$N = \frac{9 \times 40}{S} = \frac{360}{S}$$

and area cut per minute

$$= \frac{360}{S} \times F \times S = 360F.$$

The time in minutes for the surface equals

$$\frac{(L + 10) \times (B + 2)}{9C \times F} \text{ or } \frac{(L + 10) \times (B + 2}{360F}$$

If the effective speed, as is usual, is the basis, this formula becomes

$$\frac{(L + 10) \times (B + 2)}{12E \times F}$$

and with E equal to 30 feet per minute it becomes, as before,

$$\frac{(L + 10) \times (B + 2)}{360F}$$

As a basis for estimating, F may have the following values—

TABLE XVI

FEEDS FOR PLANING MACHINES

Roughing and finishing tough steel	$\frac{1}{32}$ in.
Roughing mild steel	$\frac{1}{24}$,,
Roughing cast iron and finishing mild steel	$\frac{1}{16}$,,
Finishing cast iron	$\frac{3}{16}$,,

The above feeds are suitable for medium work when the depth of the roughing cut does not exceed $\frac{5}{8}$ inch. They may be doubled if the roughing cut is about $\frac{5}{16}$ inch deep. When the capabilities of a machine are known the factor 360F may be resolved into a simple number. For roughing cast iron it may often be taken as 20.

When two tools divide a surface of width B between them each will plane about

$$\left(\frac{B}{2} + 2\right) \text{ inches.}$$

Preparation and setting occur once in each batch for each operation. The sum of the two may be taken as 20 minutes for light machines, 30 minutes for light medium (say 8 feet × 4 feet), 45 minutes for heavier and 60 minutes for large machines.

It is not easy to formulate a rule for loading and unloading because so much depends on the kind of component and the method of holding it. Nevertheless the following expression gives some guide—

$$3\,(\text{length in feet} + \text{breadth in feet}) + 12\sqrt{\text{weight in cwts.}}$$

For example, the time for a component measuring 48 inches × 36 inches and weighing 4 cwts. may be, roughly,

$$3\,(4 + 3) + 12\sqrt{4}$$
$$= 21 + 24 = 45 \text{ minutes.}$$

The length and breadth are to be measured over the extreme dimensions of the component, not over the surface to be planed.

For second operations, when the work rests on surfaces already machined, deduct 25%. When work has to be set accurately to a clock indicator add $33\frac{1}{3}$% if the clocking is on one face; if it is on two faces at right angles add 75%. These times are for one man working alone (except for crane work) and assume no delay through waiting for lifting. The same formula will be a guide for setting work on shaping and slotting machines unless it is held in a vice when (providing the vice is ready) 1 minute will suffice for ordinary work, including levelling, and 15 seconds if the setting is automatic.

For fatigue the remaining manipulation and tool allowance 15% on the floor to floor time is adequate. An extra allowance for ledges, etc., should be given as for shaping, and it must not be forgotten that although two cuts may be theoretically adequate for a given operation occasionally an extra cut will have to be taken. Trial cuts are not always a success however great the operator's skill.

Slotting machines are not nearly so adaptable or efficient as shaping machines. For that reason their use is mainly confined to tool rooms and jobbing. The rules given for shaping apply but the effective speed is usually from 15 to 20 feet per minute. If used for repetitive work such as slotting grooves, the work being held in a fixture, the allowance of 1 inch to B, which in this case is the depth of the groove should be reduced to $\frac{1}{8}$ inch. This allows for the approach, a few strokes at the end to give a good finish, and for sizing.

The feed for slotting grooves may be 0·003 inch for steel and 0·005 inch for cast iron. When slots are shaped or planed the same data can be used but slots over $\frac{3}{8}$ inch wide often require two cuts for sizing, the last cut being

with 0·005 inch feed. Slots or grooves over 1 inch wide will also require a cut to level the bottom of the groove. Thus a groove $1\frac{1}{4}$ inch wide in a steel shaft, if cut on a planing machine, will require three roughing cuts (sides and middle), a finishing cut down each side and a cut across the bottom. The width traversed across the bottom will be B + $\frac{1}{8}$ inch, less the width of the cutting tool and will be made with a hand feed of about $\frac{1}{32}$ inch. For tee slots

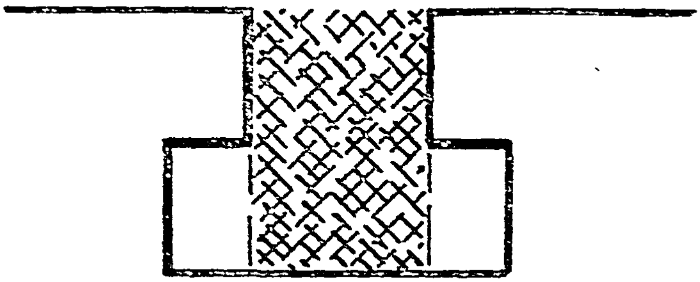


FIG. 10. TEE SLOT PLANING

allow three times the time required for cutting the central slot shown shaded in Fig. 10.

An allowance should be made when cutting convex or concave surfaces for the extra depth which the curvature may cause. Tenons may be assigned the same time as slots for sizing.

If desired the constituents of shaping or planing operations can be detailed and timed. It is more convenient, however, to allow for the manipulation, clamping and tool changing, etc., as stated previously, the work being mostly plain. If reckoned in detail the addition to width B should be halved; allow (on the average) 15 seconds for each foot of width for winding the tool back from the finishing to the commencing end of cut and 15 seconds for setting the tool to the correct height. Clamping is rather uncertain, but a reasonable time on medium and small work for placing, tightening, releasing and removing each clamp is 45 seconds if they merely need adjusting into position, and the bolts tightening to

hold the job. More usually, 90 seconds is required. For clamps which are part of fixtures 15 seconds per clamp is usually enough. Exchanging and setting a tool on a shaping machine takes 45 seconds. On a medium size planing machine 90 seconds is an average figure if everything is handy. In many workshops double these times would be required because operators' convenience has been neglected. For example, if tool shanks are of varying sizes, spanners do not fit properly, bolts have poor threads, and packing consists of assorted nuts, blocks and strips of metal, the operator cannot work efficiently.

It will be advisable to summarize the constituents for shaping, planing, and slotting work—

Preparation Setting up	once in a batch.
Loading Cutting	for each operation on each component; one load may include several components.

Fig. 11 is a key to the allowances to breadths, etc., as described previously for planing.

To the sum of the whole time for the batch add (as a rule) 15% to cover manipulation, fatigue, tool grinding, and resetting. If an operator attends to two machines add another 10%, for there will be occasions when one machine will have to wait until he is freed from the other.

Also, if the limits are extremely fine, or the work is intricate, still more time will be necessary, as mentioned on page 76.

At present the only advantage which cemented tungsten carbide tools have for shaping or planing is the durability of the cutting edges for accurate finishing, particularly on cast iron. Unless new methods are evolved it is hard to believe that great increases of planing speeds are at all likely, and high speed tool steel is quite equal to nearly all present demands when it has been properly heat treated.

A fair preparation and setting allowance for broaching operations is 20 minutes. The working cycle is very simple, consisting only of cutting stroke, return stroke, and part of the loading business. Gauging is intermittent and is sufficiently provided for in the 15% fatigue allowance.

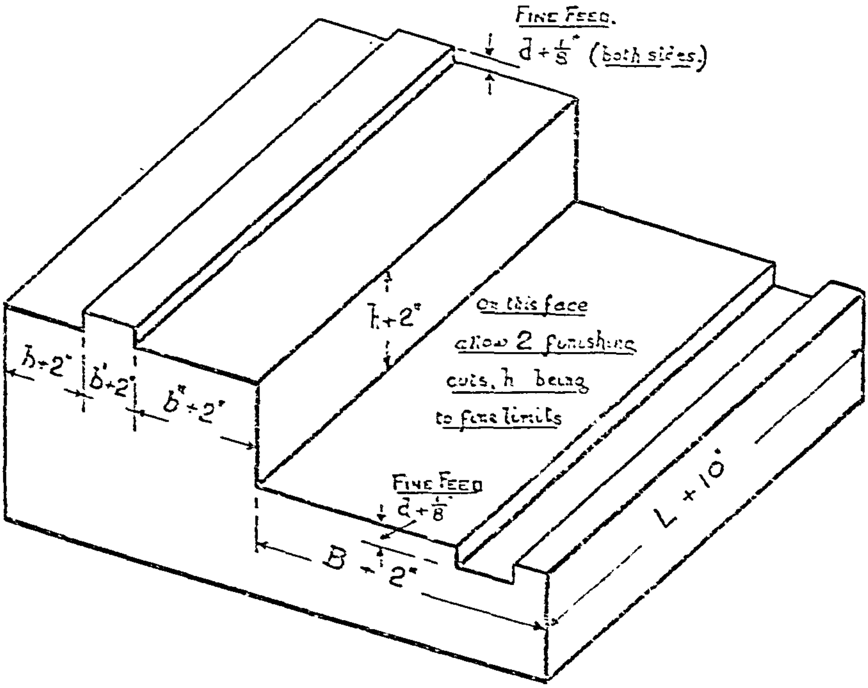


FIG. 11. KEY TO PLANING ALLOWANCES

In intensive production when the operator has a bench or stand conveniently placed to receive broaches awaiting their turn to be used and has not to fetch or carry his work, the floor to floor time per broach is, for average work—

$$\text{Cutting time} + \text{return time} + 4 \text{ seconds}$$

but do not add less than 12 seconds to the cutting time.

Both cutting and return speeds depend on the machine and must be ascertained for accurate estimates. A

suitable cutting speed for general work is 5 feet per minute. The return speed may be at 25 feet per minute. Light brass work may be done at higher speeds, but as a rule machines are used for a variety of work and not many have speed changes.

The amount removed per tooth averages 0·002 inch measured radially, i.e. 0·004 inch on diameter if there are opposite cuts. This may be increased to 0·004 inch (radially) on the average for many cast iron and brass components. The first teeth take about 25% more than the average and the last about 25% less. The last 10 or 12 teeth of a finishing broach are left parallel for sizing. As a rule the effective cutting part of a broach is about 12 inches less than its nominal length.

The pitch of the teeth should depend on the length of the hole to be broached, the longer the hole the greater the pitch. This is partly to provide chip space and partly because too many teeth cutting simultaneously would overload the broach.

For a hole of length L inches the pitch of the broach teeth should be about

$$\frac{L + 3}{10} \text{ inches.}$$

In practice a broach has often to serve for a variety of components. Not less than two teeth should be cutting (in series) at one time. When, as occasionally happens, several components can be strung on a broach the pitch of the teeth should be to suit their combined overall length but not greater than the length of the slot in any component (this being sometimes less than the overall length of the component).

At the speeds previously given it takes 54 seconds FFT for each 4-foot broach in intensive production. At the commencement of a batch or for general working 60 seconds is more suitable. For a 3-foot (nominal) broach 42 seconds and 48 seconds will be found satisfactory.

The basic time for broaching to a depth S in a hole of length L is given closely by the following expression—

$$100\ (L + 3)\ (S + \tfrac{1}{32}\text{ inch})\text{ seconds.}$$

This is for broaching at the aforesaid speeds and does not include preparation and setting, but includes fatigue. For a machine cutting at 4 feet and returning at 15 feet per minute use 125 instead of the 100 factor.

The amount $\frac{1}{32}$ inch added to S, the nominal depth of the grooves, allows for the concavity of the surface of the hole and for the broaches being slightly worn. Sometimes S is practically the real depth; it is easy to ascertain S by measurement or by simple geometry.

By the rule, to cut two keyway opposite to each other each $\frac{1}{4}$ inch deep in a hole 2 inches long will take

$$100\ (2 + 3)\ (\tfrac{1}{4} + \tfrac{1}{32})\text{ seconds}$$
$$= 141\text{ seconds.}$$

Another way of calculating the time is to ascertain the number of broaches which will be necessary, remembering that the rise per tooth can be adjusted a little to make, for instance, two broaches suffice where following the rule strictly would require two of full length and a very short one. Since the pitch of the teeth is $\frac{L + 3}{10}$ the number of effective teeth in a 4-foot broach is approximately

$$\frac{36 \times 10}{L + 3}$$

and the rise per broach will average

$$\frac{360 \times 2}{(L + 3)\ 1000} = \frac{18}{25\ (L + 3)}$$

Hence the number of broaches will be found by dividing this into the depth of the grooves. If, as in the last

examples, the (nominal) depth is $\frac{1}{4}$ inch and the length is 2 inches, the number of broaches will be

$$\left(\frac{1}{4} + \frac{1}{32}\right) \div \frac{18}{25\,(2 + 3)}$$

$$= \frac{9}{32} \times \frac{125}{18} = \frac{125}{64}$$

So two full-length broaches will do. At 1 minute a broach and adding 15% for fatigue, etc., the time works out to 120 + 18 = 138 seconds.

In modern hydraulic vertical broaching machines the broach drops free for a few inches ready for reloading. Another factor in which there has been development to save time is the design of the broaches. Just as it has been found that light cuts are inefficient with milling, so it is with broaching. There is a tendency to remove more per tooth than formerly, and to vary the pitch of the teeth, giving less space for finishing and more for roughing. This results in shorter or fewer broaches being required to cut a given depth. But broaches are too expensive to be used recklessly. That is the reason external broaching is making small headway in ordinary engineering work.

CHAPTER V

MILLING AND SAWING

An allowance of 10 minutes usually suffices for the preparation and recording time for milling operations. Setting up is extra and, for straightforward work employing one cutter and a simple fixture or vice, will occupy 20 minutes. If the fixture is very heavy more time must be given according to the difficulty of lifting.

To set a pair of straddle mills correctly within 0·002 inch will generally increase the setting time by 20 minutes. The difficulties increase out of proportion if a gang of several cutters is built up to cut within 0·002 inch relatively to each other; a definite rule cannot be stated. For intensive production such gangs are kept always ready on their arbors.

Loading and unloading times are about the same as those given in Table I for drill jigs. Many milling fixtures used for intensive production belong to Class 1 in that table but for general work Class 2 is more suitable.

The peripheral cutting speeds for milling should be the same as given for drilling in Table II when the cutters are made of high speed steel. It is sufficiently near to take $\pi = 3$ for estimating the speeds, hence

$$\text{R.p.m.} = \frac{4 \times \text{cutting speed in feet per minute}}{\text{dia. of cutter in inches}}$$

There is a strong tendency with semi-skilled labour to work at too high cutting speeds. It is a disadvantage. Feed is what matters. For intensive production the feeds in regular use for face milling and cylindrical or slab cutters of the "high powered" variety are given in Table XVII, page 88. In favourable circumstances these feeds can be increased, even doubled.

Ordinary slabbing cutters are fed at about 75% of the above rates. In the tool room and on miscellaneous

TABLE XVII

FEEDS FOR MILLING

Material	*Feed in Inches per Minute*
Aluminium	24
Brass	16
Soft bronze	12
Soft cast iron	8
Mild steel, malleable cast iron, hard bronze	6
Medium cast iron with harder edges	5
Tough steel	4

production 50% of the feeds in Table XVII is all that can generally be obtained. Besides keeping cutters sharp and employing powerful, rigid machines, it is necessary to support the work close against the cut and to use massive fixtures, otherwise there will be vibration. The depth of cut is assumed to lie between $\frac{1}{16}$ and $\frac{1}{4}$ inch. Shallow finishing cuts are often taken at a finer feed to make the work look nice. There is no need if all the conditions are made good.

Coarse feeds are better in every way than fine ones and should be obtained on repetitive work much more frequently than they are. A fine feed often gives a better optical finish to a surface because the chatter marks are sometimes closer. Far too much is made of this, for the depth of the valleys measured from the ridges is exceedingly small if the cutters are properly ground and mounted.

In the case of thin shavings, such as milling cutters produce, the power required to shave off a chip 0·006 inch thick is only about (in a general way) twice that required to shave a chip 0·002 inch thick of the same depth. There is always the possibility that the conditions will not permit the coarser feed to be taken. It takes about $1\frac{1}{4}$ h.p. to remove by milling 1 cubic inch per minute from mild steel. For cast iron about $\frac{3}{4}$ h.p. is required. The power varies greatly with the conditions but the figures given provide a good basis on which to estimate the capacity of a machine for removing metal.

The horse power at the cutting tool in belt driven machines is approximately

$$\frac{\text{R.p.m.} \times \text{dia. of lineshaft pulley} \times \text{width of belt}}{3600}$$

This applies to ordinary machine shop conditions. The factor 3600 has to be varied where, for instance, the drive is vertical and there is a great difference in the diameter of the driving and driven pulleys (as in polishing machines) or belts of special thickness or material are used. There is a difference, too, according to whether the machine is direct or countershaft driven. But for common rough and ready use where an approximate idea will suffice, the expression is satisfactory as it stands.

As an example, a lineshaft running at 270 r.p.m. has a 12 inch diameter pulley driving a milling machine; the width of the belt is $2\frac{1}{2}$ inches. Consequently the power given from the machine is

$$\frac{270 \times 12 \times 2\frac{1}{2}}{3600} = 2\frac{1}{4} \text{ h.p.}$$

As stated, the power required to remove a cubic inch of mild steel per minute by milling is about $1\frac{1}{4}$ h.p. Hence the above machine could not be expected to remove 2 cubic inches per minute because that would take $2\frac{1}{2}$ h.p. (actually, if everything were favourable and the belts tight, it might). Clearly this fact limits the feed and size of the possible cut which the machine can take.

If the cut is 4 inches wide and $\frac{3}{16}$ inch deep the volume removed per minute equals

$F \times 4 \times \frac{3}{16}$ cubic inches when F is the feed per minute.

The power required to remove that is

$$1\frac{1}{4} \times F \times 4 \times \frac{3}{16} \text{ h.p.}$$

If this equals the maximum available, viz., 2 h.p.,

$$F = \frac{2\frac{1}{4}}{1\frac{1}{4} \times 4 \times \frac{3}{16}}$$

$$= 2{\cdot}4 \text{ inches.}$$

When a cutter of diameter D, with N teeth has a cutting speed of S feet per minute and feed F inches per minute the thickness of the chip from each tooth is $\frac{\pi DF}{12NS}$

For $$S = \frac{\pi D}{12} \times \text{r.p.m.}$$

and $$\text{r.p.m.} = \frac{12S}{\pi D}$$

Therefore the number of chips per minute $= \frac{12NS}{\pi D}$

The chip thickness equals F ÷ number of chips per minute

$$= \frac{\pi DF}{12NS}$$

Thus a cutter 3 inches diameter having 12 teeth cutting mild steel at 80 feet per minute with 2·4 inches feed will produce chips of thickness

$$\frac{\pi \times 3 \times 2.4}{12 \times 12 \times 80} = 0{\cdot}002 \text{ inch nearly.}$$

This is a very common thickness, but a cutter of the same diameter with fewer teeth would, by cutting more and scraping less, do the work more efficiently at the same feed per minute.

The horsepower required to remove by milling one cubic inch per minute is approximately—

TABLE XVIII

POWER REQUIRED FOR MILLING

Material	*H.P.*
Aluminium	$\frac{1}{4}$
Soft steel	$1\frac{1}{4}$
Tough steel	$1\frac{1}{2}$
60-ton steel	$1\frac{3}{4}$
Cast iron	$\frac{3}{4}$
Soft brass	$\frac{1}{2}$
Hard brass	$\frac{3}{4}$
Copper	1
Bakelite	$\frac{1}{4}$

It is always preferable to use face cutters rather than slab

or cylindrical cutters when possible. They produce a better surface and absorb less power per cubic inch removed per minute even than "high power" cylindrical cutters.

The diameter of the cutter should be as small as convenient; a small cutter reduces, as compared with a large one, the torsion and vibration of the arbor, and the length

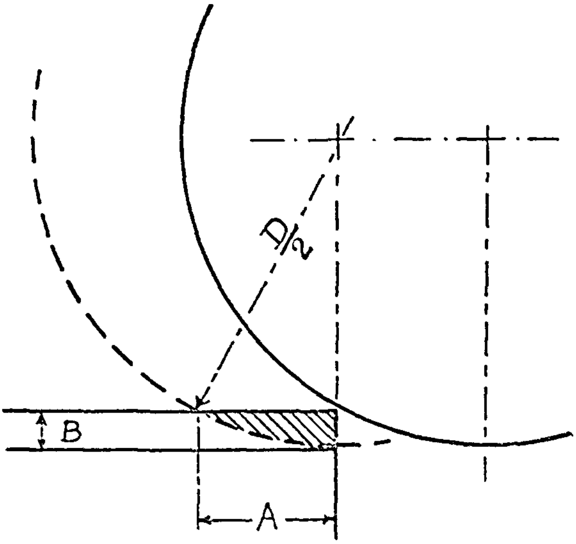


FIG. 12. MILLING—THE START

of the cut. For instance, with an 8-inch diameter face mill a machine would feed comfortably at 4 inches per minute. With a cutter 12 inches diameter, everything else being the same, the maximum feed possible was 2·4 inches per minute. The effect on the length of the cut is more apparent in gang milling or sawing, or when a groove is to be cut. The travel from the loading position to the commencement of the cut will be called the *approach*.

A further distance (Fig. 12) has still to be travelled before the full depth (or, in face cutters, the width) is attained.

It may be shown that

$$A = \sqrt{B(D-B)}$$

where B is the depth and D is the diameter of the cutter. A will be called the *start*.

$$\text{In Fig. 12 } A^2 = \left(\frac{D}{2}\right)^2 - \left(\frac{D}{2} - B\right)^2$$

$$= \frac{D^2}{4} - \frac{D^2}{4} + DB - B^2$$

$$= B(D - B)$$

$$\text{Therefore} \quad A = \sqrt{B(D - B)}$$

To this theoretical amount a little, say $\frac{1}{8}$ inch for smooth and up to $\frac{1}{2}$ inch for rough components, must be added for safety.

Besides the allowance at the start a small overrun, say $\frac{1}{8}$ inch to $\frac{1}{2}$ inch at the finishing end, is also necessary.

Face milling cutters are often set so that the front edge cuts and the back edge just, and only just, clears the surface. In other words the cutter spindle is slightly out of square but not so much that the resulting surface is appreciably "dished." Setting the spindle dead square results in criss-cross feed marks which are generally uneven and look bad.

By thus inclining the spindle the amount of travel required to finish a surface is reduced. Fig. 13 shows this clearly. When the spindle is inclined the amount of travel required to mill the length L is L + A, A (the same as the *start*) being less than the radius of the cutter according to the relation between B and that radius.

$$A = \frac{D}{2} - \tfrac{1}{2}\sqrt{D^2 - B^2}),$$

but it is easier and quicker to measure it, allowing for the start and some overrun.

When the spindle is square the travel must be L + D + overrun. When only one cut is taken over a surface the constituents are—

1. Unload and load.

2. Approach.
3. Mill surface and overrun to clear the cut.
4. Travel back to loading position.
5. Gauge.

If two cuts are required the sequence is—

1. Unload and load.
2. Adjust table (or cutter) height for rough cut.

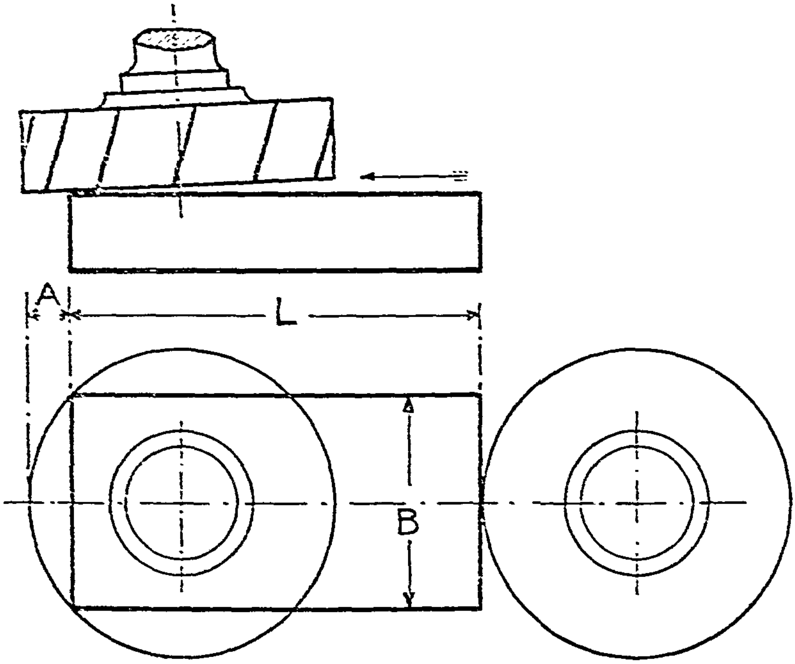


FIG. 13. FACE MILLING

3. Approach.
4. Mill surface and overrun to clear the cut.
5. Travel back until cutter is clear.
6. Adjust height for finish cut.
7. Mill surface and overrun to clear the cut.
8. Travel back to loading position.
9. Gauge.

Sometimes the last cycle may be varied when face milling by continuing the overrun in constituent 4 until the cutter is quite clear, adjusting height for the finish

cut and milling back in the reverse direction. In this way constituents 5 and 8 are eliminated but 4 is increased.

For some work constituents 2 and 6 can be omitted, the spring of the machine being enough to give a finishing cut on the return stroke. Thus constituents 5, 7 and 8 become united into one.

The approach or travelling from the loading position to the commencement of the cut may be 2 seconds as a rule, but 5 seconds if the cutter is stationary during loading.

For adjusting cutter height the time varies from 5 to 120 seconds according to the means for effecting it. On small milling machines 5 seconds is ample. Larger ones, those which will carry a 12 inch diameter face cutter for instance, require 10 seconds. The machine must be known before a definite time can be given.

The time for the return travel also depends on the machine. If a quick power return is provided only a few seconds will be required, but winding back by hand may take about 15 seconds per foot. For light lever operated machines the cycle time is often the cutting time plus 2 seconds for manipulation.

Gauging time is generally trifling and is covered in the 15% fatigue allowance unless there is something special about it.

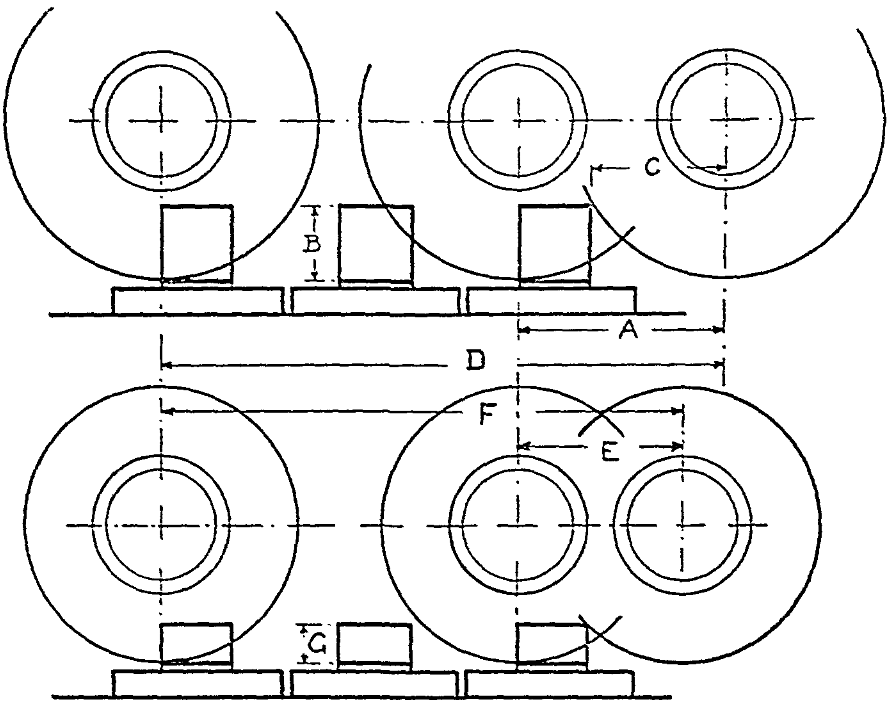
Cutting time (per cut) in seconds is evidently

$$\frac{\text{Total travel during cut}}{\text{Feed per minute}} \times 60 \text{ seconds.}$$

The total travel can be found as indicated in Figs. 13, 14 and 15. An adequate overrun must be allowed for, not less than $\frac{1}{8}$ inch for slab cutters and end mills, $\frac{1}{4}$ inch for face cutters under 6 inches diameter, and $\frac{1}{2}$ inch for larger ones. Also, when a fine accurate finish is essential, add 20% to the time of the finishing cut cycle to admit of occasionally repeating it on surfaces which are barely up to standard.

When metal castings are being machined there is always

a risk of encountering hard spots, so much so that 20% allowance may not be enough. On the other hand forgings, as a rule, should require no such extra allowance. But when quantities are very small, first-rate quality is necessary, and there are no cutter-setting gauges, trial



FIGS. 14 AND 15. SERIES MILLING

cuts have to be made. The milling machine is very easy to set nearly accurately; but a trial cut, part way, followed by a slightly deeper one all over is likely to leave a ridge; hence in those cases it is advisable to allow for two finishing cuts for the first of the components besides the 20% on the remainder, whatever the material. But not, of course, unless superfine work is really essential.

In continuous milling the components are held in

fixtures secured to a rotating table or drum. The floor to floor time per component is

$$\frac{\text{Time of revolution of table in drum}}{\text{Number of components per revolution}}$$

The determining factor is often the time for loading and unloading the components; the rate of production cannot be faster than the components can be fed into and removed from the fixtures.

In semi-continuous milling there are two stations. At one, cutting takes place while the operator loads at the other. Indexing takes place between the cuts; hence the floor to floor time equals the sum of the times for *Approaching*, *Indexing*, and either *Cutting* or *Loading* (whichever is the greater). A common time for the first two constituents is 20 seconds. Loading can be made very rapid as a rule, consequently the cycle time is often equal to the cutting time plus 20 seconds; it should be remembered that there may be several components in one fixture to share this. For any form of continuous milling it is not wise to force the cut to such an extent that the cutters need frequent re-sharpening. The speeds and feeds should be about 75% of what is recommended for ordinary milling, unless the cuts are shallow.

Series fixtures frequently involve awkward clamping and the use of excessively large cutters which (except on stiff arbors) reduce the feed and increase the length of the start. When the proportions are suitable they are great time savers. But the components from them are certain to vary a little. It is practically impossible to make the locating faces all exactly alike: hence for precision work series fixtures are better avoided.

Fig. 14 is combined with Fig. 15 but above it. There are three components in series, the depth of cut being B. From the start of the cut to reaching full depth in the first component a distance C must be travelled and when the first component has been finished the travel amounts

to A. Since the cutter commences on the second component before finishing the first time is saved. In other words, A is greater than the pitch of the component in the chain, or 3A is greater than D, the total travel for three components.

In Fig. 15 the depth G of the cut is less than B and smaller cutters are used than in Fig. 14, but the components are spaced the same distance apart. E is less than A and F is less than D, but 3E is less than F. The

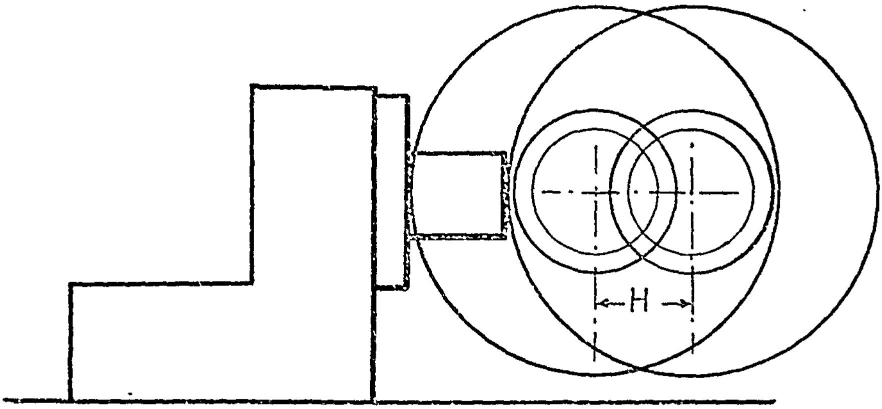


FIG. 16. MILLING—ADVANTAGES OF SIMPLICITY

milling in Fig. 15 will take less time than that in Fig. 14, but it would be quicker to mill the components singly, not in series unless manipulation be greatly increased in the former case.

This is also obvious from the fact that the first component is finished before the next is started.

Sometimes a flat is shown on a drawing where a concave surface would be equally satisfactory. If that happened to be the case with the components in Figs. 14 and 15 the quickest way of milling them would be as shown in Fig. 16. The amount of travel to complete one component is only H in that case, far less than A or E in the preceding figures. Under ordinary conditions the rate of feed through H would be the same as for A or E, consequently

much cutting time would be saved. Moreover the cutting action is better, resembling "downcut" milling.

The fixture in Fig. 16 is comparatively cheap and simple. The tool-making difficulty of providing locations in accurate alignment for several components is avoided, swarf is more easily removed and the loading time per component is likely to be less rather than more, though this depends on the method of clamping. These advantages are only slightly offset by, possibly, a small increase in machine manipulating time per component. In all these figures the bare cutting travel is indicated without any overrun or space for a safe start. But the effect of these losses is small.

The constituents for the series fixtures are

Load	Unload
Approach	Return
Mill	

For the Fig. 16 fixture the constituents are

Unload and load	Mill
Approach	Return

Milling components in parallel often present a difficulty when limits are fine. The cutters have to be accurately spaced sideways in that case and the trouble and delay in getting them set right may easily offset any gain in cutting time later. For bolt heads and similar items fine setting is not necessary. Components may be arranged to combine both series and parallel milling, there being two or more chains side by side. Squares or hexagons are often milled in that way, the chains being mounted on an indexing table and indexed through 90° or 60° for successive cuts.

Saws, too, are often mounted in parallel on an arbor for sawing components from bars. In this way extruded bars can be sawn off to length within a limit of, say, ±0·005 inch very economically. But a limit of ±0·001 inch would be extremely difficult to maintain with multiple saws. By the time the set-up was right the quantity required could probably have been cut off correctly

separately by combining a stiff saw with a side facing cutter to trim a "thou" or two off the end to eliminate any error in feeding to the stop.

The feeds for sawing may usually (except for hydraulic feed machines) be rated at 4 inches per minute for mild steel, 2·5 inches for 50-ton steel and 8 inches for brass, providing plenty of power is available and the saws are stiff enough to avoid whip. The same rates may be used for gang sawing, subject to power requirements. Thin saws will not stand more than perhaps 50% of these feeds because of "whipping." If the depth of the bars exceeds 4 inches in the case of powerful machines or 2 inches for medium milling machines the feed will usually have to be reduced in inverse proportion; i.e. a 3-inch depth would be fed at $\frac{2}{3}$ of the rate of the 2-inch deep bar. Small bars can often be grouped together and cut in one pass. If small bars are cut singly, the feed may sometimes be increased in inverse proportion, but it is unsafe to assume that before discovering the capabilities of the machine.

When bars are cut off in the stores the operation generally includes extracting them from the racks, carrying them to the machine and counting and weighing the pieces cut off. The piece-work allowances depend on the facilities provided and these vary greatly. Each case must be studied, taking into consideration the quantities of one section and length, how many machines a man has to attend to, whether his work is regular or intermittent, and so on.

In intensive production the actual times for sawing off mild steel billets, including weighing, transport, etc., with a man working one machine, may be taken as—

$$0{\cdot}12 \text{ minutes per square inch} + 0{\cdot}5 \text{ minutes.}$$

For this purpose round bars may be taken as square. Thus for sawing off, weighing, etc., pieces from a 3-inch diameter bar, the time will be $3^2 \times 0{\cdot}12 + 0{\cdot}5$

$$= {\cdot}58 \text{ minutes per piece.}$$

Some of the new hydraulic machines are 30% faster than the mechanically operated machines on which the above formula is based and enable that proportion of time to be saved because they are semi-automatic. If the bars are nested so that several are cut simultaneously use 0·12 minute for each inch in their combined area but reduce 0·5 to 0·3 for each bar.

For sawing off under regular production conditions on a medium-powered milling machine the actual time in seconds for sawing off mild steel may be as in Table XIX.

TABLE XIX

SAWING MILD STEEL ON MILLING MACHINES

Size of Bar	Load Whole Bar	*Per Billet*	
		Manipulation	Cutting
4 in. . . .	90	30	140
3 in. . . .	60	30	90
2 in. . . .	30	20	40
1 in. . . .	20	15	20

The size of bar is for square or round bars or flats grouped to make the equivalent section. Loading time for the whole bar is given separately because its effect on each cut off depends on the number of pieces each length will make. If the ends of the bars are not square to start with an extra cut is necessary to square them. Manipulation includes feeding to stop, clamping, and machine handling. Owing to the saws cutting in arcs the length of the cut is greater than the thickness of the bar. The rates for tubes may be taken as about the same as for solid bars; there is less metal to remove, but it gives far more trouble. For bars of other material the cutting time will vary in proportion to the feeds in Table XVII; the other constituents will be as in Table XIX.

While on the subject of cutting off it will be as well to

include hack-sawing times. With efficient machines and saws the actual basis time per piece, including weighing and transport, may be 0·3 minute per square inch + 0·2 minute per piece. "Per square inch" means sectional area for square bars, and round bars are to be reckoned as square for the purpose.

Thus the basic time for pieces $1\frac{1}{2}$ inches diameter would be $\frac{3}{2} \times \frac{3}{2} \times 0{\cdot}3 + 0{\cdot}2$

$$= 0{\cdot}92 \text{ minute.}$$

All the above formulæ are for general application where lengths vary from an inch to 4 or 5 feet and from mild steel to alloy steel before heat treatment, these being the usual requirements. An allowance of 15% is adequate for preparation, recording, setting up, and fatigue, unless the quantities are small. Should they be generally in half dozens or thereabouts the allowance should be increased to 30%; and for tool room and similar work where only one or two of a kind is the rule 50% is necessary. Where the conditions are such that efficient work is impossible it is not uncommon for treble the above times to be found necessary.

Many milling operations involve *indexing* as a constituent. The average time for hand indexing with a notched plate is 5 seconds. For closely-spaced notches and simple movements 3 seconds suffice; a long sweep and a quick clamping device will take 8 seconds on light work. Power indexing takes from less than one to several seconds according to the type, size, and age of the machine. The time must be ascertained for accurate estimating.

With the indexing are always associated the approach and the travel back to clear the cutter and they may be reckoned as one constituent, the times being based on the foregoing for milling machines or on a study of the gear-cutting machine as the case may be.

The spaces between gear teeth being deep grooves, the cutting travel is always much greater than the length of the teeth as already shown.

When spiral teeth are hobbed the amount of cutting travel is further increased by approximately 2A where A is measured as shown in Fig. 17. This assumes that 4 teeth are engaged simultaneously by the hob. It is a very rough rule. Still, it is near enough for many purposes.

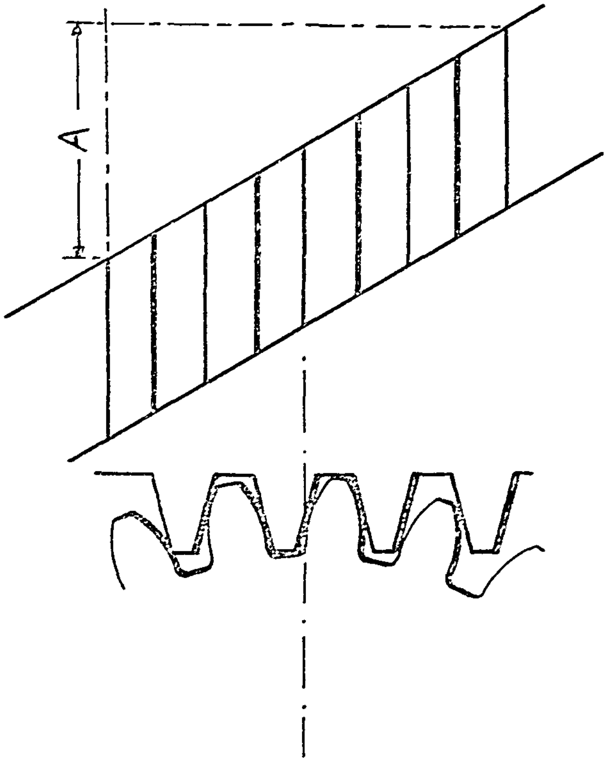


FIG. 17. TRAVEL OF HOBS

The rate of feed for hobbing may be that which would be used for ordinary gearing divided by the number of teeth in the wheel. Thus, if 5 inches feed per minute would be satisfactory when the teeth were cut singly, $\frac{5}{28}$ inch feed would be right for hobbing if there were 28 teeth. This supposes a hob with a single start. For fine teeth multiple start hobs ought to be used and then the rate of feed can be multiplied by the number of starts. In the example if the hob had 7 starts the rate of feed would thus become $1\frac{1}{4}$ inches per minute. Hobbing eliminates indexing time.

Suitable feeds for ordinary gear cutting are given in Table XX, page 104. The manner in which the work is supported makes a great difference to possibilities in this respect.

The table gives feeds in inches per minute. The roughing cut is assumed to leave about 0·015 inch (measured radially in setting the cutter depth) for finishing the smaller pitches and up to 0·040 inch for the large pitches. Under very favourable conditions roughing feeds may be 50% faster than the table gives. If only one cut is taken the feeds may be about 80% of those given in the table.

The remaining constituents for gear cutting by milling call for no special comment. A man can work several machines simultaneously.

Thread milling feeds may be as given in Table XVII for ordinary screws. An allowance of 6 seconds usually covers the approach and sinking to full depth. The constituents are—

Load
Approach and start
Feed through one turn plus (about) $\frac{1}{2}$ inch
Withdraw for reloading
Gauge occasionally—say, 10%

An operator usually looks after at least two machines. When worm threads are milled the length of the grooves must be calculated or measured and an extremely liberal allowance made for the travel at the start between commencing to cut and reaching the full depth. Indexing must be allowed for when there are multiple starts. The workshop is the best place for finding the real length of cutter travel for each start. The feeds in Table XX are suitable.

Milling cast iron, bronze, and brass with tools tipped with tungsten carbide is very successful. On aluminium it is not so good, and not many use it for steel.

Whereas suitable feeds per tooth with cutters of

high-speed steel range usually from 0·008 to 0·016 inch, according to the depth of cut, its breadth, and the power available, the feed per tooth with tungsten carbide may well be from 0·005 to 0·010 inch in similar circumstances. But the speed may be at least three times as great. Thus, in general, the feed per minute is doubled when milling with tungsten carbide.

Sometimes carbide tools are used with speeds and feeds not greatly different from those suitable for high-speed steel. The advantage lies in the greater durability of the cutting edge. On cast iron it will last fcr four or five times as many components and on the brasses it is better still.

TABLE XX

FEEDS FOR GEAR-CUTTING

Dia. Pitch	*Roughing*				*Finishing*			
	Brass	Cast Iron	Mild Steel	Tough Steel	Brass	Cast Iron	Mild Steel	Tough Steel
2	—	5	4	3	—	6	6	4½
3	—	5¼	4¼	3¼	—	6½	6½	6
4	—	5½	4¼	3½	—	7	7	7
6	—	5¾	4½	3¾	—	7½	7½	7½
8	10	6	4¾	4	16	8	8	8
10	12	6½	5¼	4¼	16	8½	8½	8½
			One Cut					
12	8	5½	4½	3½	—	—	—	—
16	10	6	4¾	3¾	—	—	—	—
20	12	6½	5	4	—	—	—	—

Against this advantage must be set the high first cost, the fragility of the tips when slightly abused and the trouble in grinding. On the whole carbide tools are suitable at present only for special cases; for instance, where quantities are large, materials are rather hard and machines are stiff and with plenty of power. If high speed steel stands up to the work and absorbs all the machine power nothing is to be gained by changing to tungsten carbide.

CHAPTER VI

TURNING

THE preparation time for centre lathe work including preparation, recording and setting up as defined in pages 39 and 48 averages 20 minutes for small lathes, 30 minutes for a 12-inch centre lathe (i.e. 24-inch swing), and 40 minutes for heavy lathes. If gears have to be set for screw cutting allow another 15 minutes for simple trains and 30 minutes otherwise, unless no new calculation is required, when 10 and 15 minutes respectively are ample.

When work is done between centres the loading constituent includes placing the carrier on the work, greasing the centre, putting between the centres, adjusting the tail stock, and the reverse sequence. The inclusive time is

TABLE XXI

CHUCKING TIMES

(The times are in seconds, and include loading and unloading)

Self-centring Jaws	*Weight of Components*			
	Up to 2 lb.	7 lb.	20 lb.	60 lb.
A. Rough castings, etc.	30	60	120	180
B. Special jaws gripping surface already turned	20	45	90	120
C. As at *B* and setting face true within ± 0·001 in. up to 10 in. dia. and within ± ·002 in. over that	75	150	240	360
Independent jaws				
D. Rough casting, etc.	60	120	210	300
E. Chuck and set true as at *C*, but on dia. and one face	160	360	600	900

30 seconds for light pieces easily manipulated with one hand. If two hands are required 60 seconds is adequate unless the weight is over 60 lbs. and either an extra hand or lifting tackle is necessary. Then the time must be judged according to the facilities provided. If the work is done on a mandrel increase the above time by 20 seconds for light and 40 seconds for medium components which weigh, with mandrel, not over 60 lbs.

The exchange of a face plate for a chuck takes about $1\frac{1}{2}$ minutes for small lathes and up to about 3 minutes for medium size lathes. Changing speeds or feeds are better included with the fatigue allowance (see page 135). Tool changing may be similarly included but often is such a large item that it has to be reckoned separately.

When components are held in lathe fixtures there is seldom much chance of using quick-acting clamps. The times given in Class 3, Table I, generally apply if another 20 or 30 seconds are added for each clamp over the first, according to the size. When fixtures do not set the work true automatically another 15 seconds or so must be added, by judgment, to suit the method of adjustment.

The figures in Table XXI are good guides for general use under ordinary conditions. There are specialists engaged in intensive production who can easily chuck and set work true in half the times given for C and E.

Although the times are given in accordance with weight, the shape of the components and manner of gripping them often make modifications necessary. Smaller times can be allowed for heavy components which are solid and compact—often 30% less.

When the diameter of the turned surface is D inches and its length is L inches the general formulæ relating to cutting speed are—

$$\text{R.p.m.} = \text{cutting speed in feet per minute} \times \frac{12}{\pi D}$$

Cutting speed in feet per minute

$$= \frac{\pi D}{12} \times \text{R.p.m.}$$

Feed per minute = r.p.m. × feed per rev.

Cutting to turn 1 inch length

$$= \frac{1}{\text{R.p.m.} \times \text{feed per rev.}} \text{ minutes}$$

$$= \frac{\text{number of cuts per inch}}{\text{R.p.m.}} \text{ minutes}$$

Cutting time in minutes to turn length of L inches

$$= \frac{\text{L} \times \text{number of cuts per inch}}{\text{R.p.m.}}$$

$$= \text{L} \times \frac{\pi D}{12} \times \frac{\text{number of cuts per inch}}{\text{cutting speed}}$$

$$= \frac{\text{L} \times \pi D}{12} \times \frac{1}{\text{feed per rev.} \times \text{cutting speed}}$$

$$\frac{\pi}{12} = 0{\cdot}26 \text{ (approx.)} \qquad \frac{12}{\pi} = 3{\cdot}8 \text{ (approx.)}$$

For many workshop speed calculations it is near enough to take $\pi = 3$.

For practical use further reasonable assumptions may be made to suit restricted conditions in such a way that the formulæ become extremely simple. As an instance, 50 cuts per inch is a reasonable standard feed for turning mild steel on lathes up to about 8 inches centre height.

The cutting speeds for turning may be those given in Table II. They can be largely increased for light cuts, as will be indicated later.

The speed is the rate at which the turned surface passes the point of the tool. Unless there is so much metal to remove that several heavy cuts are necessary, the finished

(not the rough) diameter should be the basis for computing cutting speed and this will invariably be understood. The cutting speed being 90 feet per minute, the cutting time for turning a length of L inches

$$= \frac{L \times \pi D \times \text{number of cuts per inch}}{\text{cutting speed} \times 12}$$

$$= L \times D \times \frac{\pi}{12} \times \frac{50}{90}$$

$$= \frac{L \times D}{7} \text{ nearly.}$$

Thus the cutting time for turning mild steel 3 inches diameter for a length of 28 inches would be, for one cut—

$$\frac{28 \times 3}{7} = 12 \text{ minutes.}$$

Similar modified formulæ can easily be devised to suit other materials and conditions and are most valuable to rate fixers. There is always a danger, if such formulæ are used by unpractical men, that they may be applied where conditions are unsuitable. On the whole it is best to use the general formulæ, simplifying the calculation by reference to a table which relates diameters, r.p.m. and cutting speeds. That in Table XXII will be found convenient and it is easy to extend its range.

To turn a length L inches the tool always has to travel more than that distance. An allowance of $\frac{1}{4}$ inch will suffice for work up to about 6 inches diameter. For larger work allow $\frac{1}{2}$ inch unless the cut is light.

When large rough forgings are to be turned 1 inch or even more will not be an excessive amount to add to L. These allowances are for repetitive work where the tool is set to cut the correct diameter by a stop. If the size has to be found by trial add another 1 inch to the length L for moderate and $1\frac{1}{2}$ inches for fine limits.

TABLE XXII

Turning Speeds for Various Diameters

	Feet per Minute											
	15	20	25	30	35	40	50	60	70	80	90	100
	Turns per Minute											
⅛	458	611	764	916	1,069	1,222	1,528	1,833	2,139	2,444	2,750	3,056
3/16	306	407	509	611	713	814	1,018	1,222	1,427	1,629	1,833	2,037
¼	228	306	382	458	535	611	764	916	1,069	1,222	1,375	1,528
⅜	153	204	254	306	357	407	509	611	713	814	916	1,018
½	115	153	191	228	267	306	382	458	535	611	688	764
⅝	92	122	153	183	214	244	306	367	428	489	550	611
¾	76	102	127	153	178	204	254	306	357	407	458	509
1	57	76	95	114	134	153	191	229	267	306	344	382
1¼	46	61	76	91	107	122	153	183	214	244	275	306
1½	38	51	64	76	89	102	127	153	178	204	229	254
2	29	38	48	57	67	76	95	114	133	153	172	191
2½	23	31	38	46	53	61	76	92	101	122	137	153
3	19	25	32	38	44	51	64	76	89	102	115	127
3½	16	22	27	33	38	44	54	65	76	87	98	109
4	14	19	24	29	33	38	48	57	67	76	86	95
5	11·5	15·3	19	23	27	30	38	46	53	61	69	76
6	9·5	12·7	15·9	19	22	25	32	38	44	51	57	64
8	7·2	9·5	11·9	14·3	16·7	19	24	29	33	38	43	8
10	5·7	7·6	9·5	11·5	13·4	15·3	19	23	27	31	34	38
12	4·7	6·4	7·9	9·5	11·2	12·7	15·9	19	22	25	29	32

For example, the cutting time in minutes for turning a length of 6 inches on a cast iron piece 12 inches finished diameter, taking one cut $\frac{3}{16}$ inch deep at 50 feet per minute and 40 cuts per inch, would be $\frac{(6 + \frac{1}{2}) \times 40}{15 \cdot 9} = 16 \cdot 4$ minutes if the tool were already set. But if trial cuts were taken the time would be

$$\frac{(6 + 1\frac{1}{2}) \times 40}{15 \cdot 9} = 19 \text{ minutes.}$$

Of course with coarse limits fewer trials would be needed and less than 1 inch allowance would suffice.

The rate at which metal can be removed by turning varies with the power and stiffness of the machine, the stiffness of the work, the kind of material being cut, and the quality of the cutting tool. Nevertheless, it is possible to state fairly definite rules based on good practice.

First of all, the great majority of roughing cuts do not exceed $\frac{3}{16}$ inch in depth. Then, although there are plenty of smaller and larger lathes, those with centre heights of 8 or 10 inches are the commonest. It will be assumed that the cutting tools are of one of the best kinds of high speed steels, correctly heat treated and ground properly at the most efficient angles. Lastly, as a guide to the stiffness of the work, Fig. 18 will be found useful.

It applies to mild steel shaft turned or ground between centres. Diameters are measured vertically and lengths horizontally, both in inches. The curves are based on stress for small shafts and deflection at the centre for long shafts. The top curve shows the relation between diameters and lengths for stiff shafts, the middle curve for medium and the lower curve for weak shafts. A stiff shaft will sustain a cut $\frac{3}{16}$ inch deep 0·020 inch feed, a medium shaft one of $\frac{1}{8}$ inch deep and a weak shaft one of $\frac{1}{32}$ inch deep also with 0·020 feed, without a steady. The diameters are those *after* the cuts have been taken.

In the case of shouldered shafts, if the smaller diameter

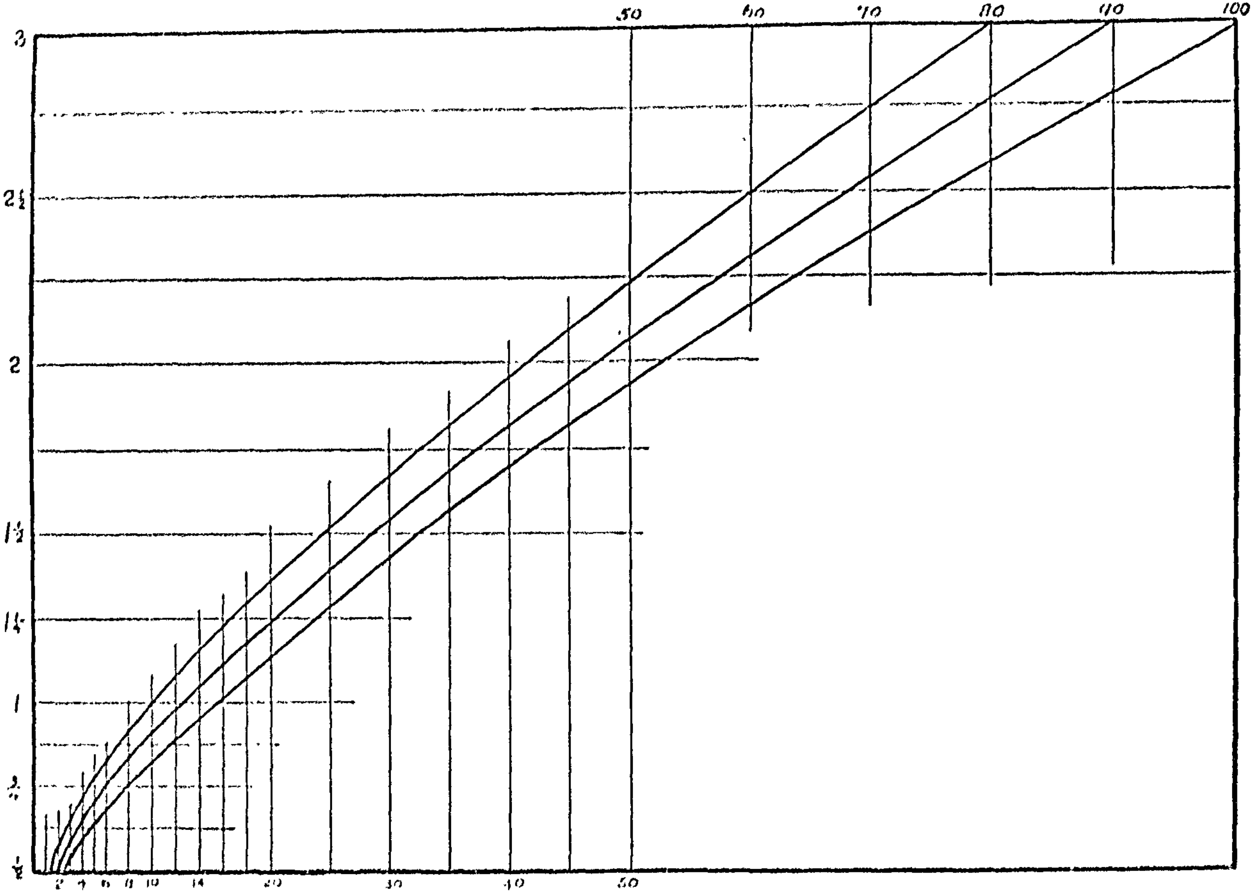


FIG. 18. SHAFT STIFFNESS

is near the centre that diameter determines the stiffness. If the smaller diameter is at an end the larger diameter determines the stiffness provided the smaller diameter does not extend from the end for a greater distance than one-third of the limiting graphed length of an equally stiff shaft of the smaller diameter. For example, a 3-inch diameter shaft can be reduced to $2\frac{5}{8}$ inches diameter with one cut at 0·020 inch feed, without a steady, providing the length of the shaft does not exceed 80 inches and the $2\frac{5}{8}$ inches length is not more than $65 \div 3$, or, say, 22 inches. Similarly a shaft 1 inch diameter 15 inches long can be reduced with one cut to $\frac{3}{4}$ inch diameter, without a steady, the feed being 0·020 inch, for a distance of 2 inches. Reference to the graph shows by the middle curve that a 1 inch diameter shaft will sustain the medium cut $\frac{1}{8}$ inch deep without a steady when it is rather more than 12 inches long. The limiting length of the $\frac{3}{4}$ inch shaft is similarly 6 inches. Hence the maximum length of shoulder $\frac{3}{4}$ inch diameter is $6 \div 3 = 2$ inches; and since this is close to the end one may safely assume that a 15 inch instead of 12 inch length of 1 inch diameter will stand the load without steadying, it being only 25% longer, which is about the limit in the circumstances.

The pressure on the cutting edge of the tool varies with the area of the cut, i.e., depth of cut $\times$ feed per revolution. With a cut $\frac{3}{16}$ inch deep $\times$ 0·020 inch feed in mild steel the load on the tool is about

$$\frac{3}{16} \times \frac{1}{50} \times 115 \text{ tons} = 0{\cdot}43 \text{ tons.}$$

Similarly for a cut $\frac{3}{32}$ inch deep $\times$ $\frac{1}{32}$ inch feed the load will be $\frac{3}{32} \times \frac{1}{32} \times 115$ tons $= 0{\cdot}34$ tons.

The pressure per square inch is usually taken at 150 tons for hard steel and 80 tons for cast iron, as found by numerous experiments. Within reasonable limits the basic speeds of Table II will apply for considerable variations of depth of cut if the area of cut is kept fairly constant. For instance, with a depth of $\frac{3}{32}$ inch and a feed of 0·04 inch,

90 feet per minute will still be suitable for turning mild steel. But when the area of the cut is much altered the appropriate speed is changed too for steels. Cast iron cutting speed is not so much affected. Unless the quality of the iron is known it is best to assume a cutting speed of 50 feet per minute for all conditions, except when extremely heavy cuts are made. Cutting speeds for steel may vary with the area of the cut as shown in Table XXIII. A change in the quality of the cutting material or in the quality of the material being cut makes an appreciable difference to the possible speeds, so the figures can only be used as a guide.

TABLE XXIII

AREA OF CUT AND CUTTING SPEEDS

Area of Cut	*Cutting Speeds in Feet per Minute*			
	Mild Steel	Tough Steel	50-ton Steel	Cast Iron
·001	150	100	75	60
·002	110	80	60	50
·004	90	60	45	50
·008	75	50	35	45
·016	60	45	30	35

It was stated above that $\frac{3}{16}$ inch $\times$ $\frac{1}{50}$ inch cut in mild steel required a tool pressure of 0·43 tons. This load through 90 feet per minute equals about 2·6 horse power. Obviously the belt power supplied to the machine must be at least that amount or the cut cannot proceed. Again, such a cut will result in removing just over 4 cubic inches per minute. Hence the power to turn 1 cubic inch per minute from mild steel is about 0·65 h.p., or 1 h.p. will remove about $1\frac{1}{2}$ cubic inches per minute. Similarly 1 h.p. will remove about 1 cubic inch per minute from tough steel, $\frac{3}{4}$ cubic inch from 50-ton steel, 2 cubic inches from cast iron, and 4 cubic inches from brass.

Feeds for facing may be the same as for straight

turning; the speed may be that which suits the largest diameter of the facing, though a little higher than for straight turning is permissible since it is rapidly decreased as smaller diameters are reached. It does not pay to change speed while facing on ordinary lathes unless the mean diameter of the facing is over 8 inches and the maximum exceeds the mean diameter by at least 40%—the time for belt shifting will exceed the gain in cutting time.

Exchanging tools involves manipulation of the tool rest in addition to making the exchange. The time, including manipulation, averages $\frac{1}{2}$ minute for light lathes with American type toolposts. English type toolposts require longer; 1 minute is a fair time for medium and $1\frac{1}{2}$ minutes for heavy lathes. Indexing a square toolpost to present a different tool takes from 10 to 15 seconds, according to size. In chuck work the time may be more, as will be seen later when considering capstan lathes.

When tools are exchanged trial cuts and gauging become necessary. As already mentioned, trial cuts may be accounted for by adding 1 inch to the nominal length of the work. Winding the saddle along the bed varies considerably with different machines; about 5 seconds per foot is, perhaps, an average time. But fatigue and tool allowances may usually be reckoned to contain this.

Taper turning may be done at the same rates as straight turning when a taper attachment is used. For prolonged hand feed allow $\frac{1}{16}$ inch depth and $\frac{1}{64}$ inch feed on light lathes and $\frac{3}{32}$ inch depth and $\frac{1}{64}$ inch feed on heavy lathes.

The feeds and speeds for boring may be as for turning, but the depth of cut is usually less owing to the overhang of the boring tool. Generally, unless the amount to remove is great, or the hole is very long, one cut more than would be required for turning off the same amount of metal is sufficient. Whereas for turning to coarse limits (+ 0·005 inch and over) one roughing and one finishing cut will frequently suffice, three cuts would be necessary for

boring. Similarly work which is turned to fine limits will require, commonly, a roughing, a semi-finishing and a finishing cut. But for boring to the same limits, with the same amount to remove, four cuts should be allowed; or, in the case of small holes, two single point cuts followed by reaming.

With horizontal boring machines the speeds and feeds apply as for lathes, and Fig. 18, relating to stiff and weak shafts, is also helpful, boring bars being shafts. In repetitive work where fixtures are used, the work setting time is short—it must be judged by the circumstances—and the cutter adjusting time is negligible if the cutters can be left permanently in the boring bars.

Any boring cutter that is removed from the bar will need setting time and trial cuts as for lathe work. Moreover, gauging becomes a difficulty; but the general rule given in the notes relating to Table XXIV applies with one modification: instead of "rough dimensions will need about half these times" read "fine dimensions will need double these times."

In the case of miscellaneous boring the preparation and setting up times can be estimated only when the conditions are known. As a rule a horizontal boring machine used on general work cuts only from 15% to 20% of its time. Most of the work goes in improvising tools, finding or making packing, and setting true the work and boring bars.

TABLE XXIV
GAUGING TIMES

Instrument	Size	Fine Limits	Ordinary Limits
External micrometer . .	Up to 1 in.	10	5
,, ,, . .	,, 2½ in.	15	10
,, ,, . .	,, 6 in.	20	15
Internal micrometer . .	,, 6 in.	30	20
Snap gauge . . .	,, 3 in.	10	5
,, ,, . . .	,, 8 in.	15	10
Plug gauge . . .	,, 2½ in.	10	5
,, ,, . . .	,, 6 in.	15	10

The above figures are in seconds and give an indication of the time required for each application of a gauge. Fine limits are those for ball race fits or extremely accurate tool work. Where there are trial cuts allow three applications for fine and two for coarse limits. Long shafts require gauging at several places. But in most cases, for ordinary work not intensively manufactured, the following rule for gauging time will be satisfactory: for each dimension to be gauged or measured allow $\frac{1}{2}$ minute, and for every foot in that dimension, whether diameter or length, add a further $\frac{1}{4}$ minute. Rough dimensions will need about half these times (compare with previous note regarding boring). It must be remembered that except in intensive production a dimension commonly has to be measured at least twice.

If a steady is to be used allow 10 minutes for setting it in the first place and 3 minutes for subsequent adjustments. Any turning necessary before steadying will be either with light cuts or at the end where the centre already provides sufficient support. For applying a steady already set for size allow 1 minute when necessary.

The shaft in Fig. 19 could be made from a bar $3\frac{1}{8}$ inches diameter or from a forging. It is on the border line where a slight change in circumstances would make either method the cheaper. Suppose it is to be made of tough steel, and that the $3\frac{1}{8}$-inch diameter bar already heat-treated costs $1\frac{1}{2}$d. per lb. It will weigh 132 lbs. and will cost 16/6. The forging will probably weigh 70 lbs. If it cost 3d. per lb., supplied heat-treated and straightened, its price will be 17/6. The weight of 70 lbs. is based on the forging being $2\frac{1}{4}$ inches diameter, except at the collar. It could be $2\frac{1}{8}$ inches diameter if there were large numbers to make; for the present purpose let the quantity required be three. The objection to $2\frac{1}{8}$ inch diameter for small quantities is the difficulty there probably would be in maintaining concentricity on each side of the collar; the straightening time would be excessive or else the shafts would fail to

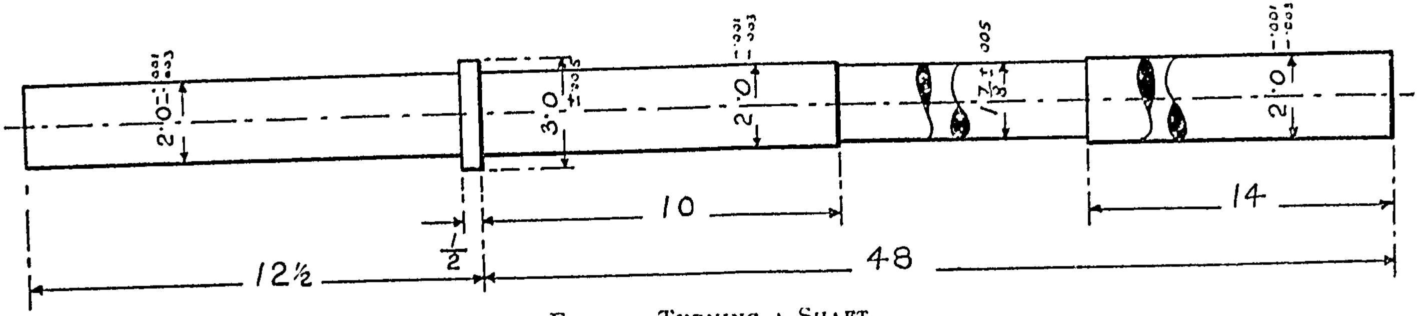


Fig. 19. Turning a Shaft

clean up. With large quantities this difficulty would be overcome, resulting in a saving of about $7\frac{1}{2}$ lbs. weight and 1/10 in the price of each forging.

The bar may be stocked in, say, 12-feet lengths. A 12-feet length will make two components and leave an odd length of less than 2 feet. Will that be usable? Cutting off has to be paid for. Machining will take longer, perhaps —not necessarily—as will be shown later.

On the other hand, it is likely that the forging will need some straightening when the turner gets it. The turner's idea and the smith's of what straightening means may not be identical. Again, the length of the forging is almost certain to be excessive near the axis through the rough cut off made in the smithy. This will mean, very likely, having to centre the ends twice, once for facing (or even parting off) to length and afterwards for turning. Moreover, near the collar the forging will taper down gradually, not abruptly, to the $2\frac{1}{4}$ inch diameter, a fact which will increase turning time.

However, let forgings be decided upon and delivered to the machine shop for turning on an ordinary single post lathe. Bars would be sawn off to the desired length, leaving only about $\frac{1}{16}$ inch for facing the ends. They could be centred on a centering machine by a semi-skilled man at the rate of about $\frac{3}{4}$ minute an end. By way of contrast it is worth mentioning that in intensive production, using a double-ended machine, $\frac{1}{2}$ minute would be plenty of time for centre drilling both ends. But the forgings will have rough ends and must be faced to length before centering permanently. In the circumstances it will be convenient for the turner to do the whole of the work.

First, he will flatten the centre, if necessary, for convenience in marking; second, he will mark off the centres; third, he will centre-punch them. Considering their weight 10 minutes will not be too long for the three shafts, especially as the necessary tools have to be laid ready at the start and then put back into their customary places.

Lest the picture be drawn too black let it be supposed that a self-centering chuck is ready for use on the lathe; then, by chucking one end, the other can be supported by the centre while a short length is turned to, say, $2\frac{1}{32}$ inches diameter for running in the fixed steady. If the end is smooth and round this may not be necessary, but it is certainly safer. When the steady is applied the end can be faced to suit the forging. The 10 minutes for setting up the steady in the first place should be reckoned here, but the turning time need not be included because this preliminary work will save time later. After the facing is done the permanent centre can be drilled from the tail stock. A fair time for one end will be—

	Mins.
Chuck one end and support the other on centre . .	1·0
Set tool for turning and facing (2 ÷ 6 ends) . .	0·33
Turn end $\left(2 \times \frac{2\frac{1}{2} \times 32}{114}\right)$	1·4
Mark position of end to suit forging	0·75
Steady (application only)	1·0
Face end $\left(\text{assume 3 cuts, } 3 \times \frac{1\frac{1}{2} \times 64}{114}\right)$ . . .	2·5
Replace centre by drill chuck with centre drill . .	0·5
Centre drill	0·25
Replace centre	0·5
Remove forging from chuck	0·5
Total	8·73

Six ends will take $6 \times 8{\cdot}73 = 52{\cdot}38$ min.

Some straightening must also be allowed for. On a proper press $1\frac{1}{2}$ minutes per shaft would suffice. When the turner does them he may have to collect tackle and is likely to spend at least 15 minutes in straightening the three.

Thus the 6 forgings will take for the preliminary work—

	Mins.
Fixing steady in first place (1 min. for 1st shaft already included)	9·0
First centering	10·0
Facing and final centering	52·38
Straightening	15·0
	86·38

or, near enough, 86 min.

The bars would take for

	Mins.
Cutting off	7
Centering	$4\frac{1}{2}$
	$11\frac{1}{2}$

The short time required for skimming the end faces of the bars for the present can be neglected. Thus far the bars have an advantage $74\frac{1}{2}$ minutes. If one hour is equivalent to 4/- on the chosen lathe each bar is about 2/8 cheaper than the forging up to this stage, since it cost 1/- less in the first place. The question now is: Will the time saved in turning the forging be worth more than 2/8? In this example let the lathe have speeds of 80, 114, 160 and 220 r.p.m. among others. The turning time will naturally depend considerably on the available speeds. If they are unknown the ideal speeds of Table II should be the basis for the rate fixer's instructions, but for estimating a price for quoting a customer it is advisable to add a percentage on the basis time to cover what may be termed the ignorance factor. This is extra to and not to be confused with the fatigue and other allowances. As much as 20% is sometimes allowed. For simple work such as these shafts 10% should be plenty. Further, suppose the lathe has a 3 h.p. drive, that it can feed by power at 16 and 32 cuts per inch, and feed and speed changes can be quickly made.

Of course all the points mentioned here will not be considered for every estimate; one problem well studied is better than many superficially examined.

By Fig. 18 the shaft is very weak, hence a travelling steady will be necessary for roughing the long end.

The cutting constituents for roughing will be—

A. Turn long end. The finished length to the collar is 48 inches. Allow 1 inch extra for trial cuts at the start and another 3 inches for extra cuts which may be necessary due to the swelling near the collar. The total is 52 inches.

B. Turn collar and face one side. The total length will probably be 2 inches for the top diameter. Facing will include turning a short length of the smaller diameter, say 3 cuts averaging 1 inch each allowing for irregularities and a dwell at the ends, making a total of 5 inches.

C. Turn short end. Working as at A the total will be 16 inches.

D. Face collar as at B. Total length equals 3 inches.

The speed of 114 r.p.m. will be right for cutting A and C at 60 feet per minute. This combined with $\frac{1}{32}$ inch feed through a total length of 68 inches gives a time of

$$\frac{68 \times 32}{114} = 19{\cdot}1 \text{ minutes.}$$

Similarly B and D at 80 r.p.m. (rather fast but near enough) will take

$$\frac{8 \times 32}{80} = 3{\cdot}2 \text{ minutes.}$$

The total cutting time = 22·3 minutes.

But will the lathe be powerful enough to remove metal at this rate of about 3 cubic inches per minute? Since 1 h.p. will remove about 1 cubic inch of tough steel per minute, the 3 h.p. provided will just suffice.

In anticipation of A the shaft will have to be placed between the centres. For C it must be reversed; it will be removed from the centres and laid down when completed. The times per shaft will be—

	Mins.
Loading time	2·0
Tool setting	1·0
Steady (two applications)	2·0
Gauging—roughly for diameters and lengths	2·0
Total	7·0

In addition there is the first setting of the steady of which 1 minute has already been included, leaving 9 minutes to be divided among 3 shafts, or 3 minutes

each. The total handling time is, therefore, 10 minutes per shaft.

	Mins.
Handling time	10
Cutting time.	22·3
Preliminary work $\frac{86}{3}$ . . .	28·7
Total . . .	61·0

At 4/- an hour this is worth 4/1. Hence the total cost of the forging up to this stage is 17/6 + 4/1 = 21/7.

If the bar were turned on the same lathe the handling would take more than 10 minutes on account of the extra weight—say 15 minutes. Since the removal of 3 cubic inches per minute is the utmost the lathe can do, that gives a ready way of ascertaining the cutting time. The weight of the bar will be 132 lbs. When it has been rough turned its weight will be 75 lbs. less, which, at 0·28 lbs. per cubic inch is equivalent to 270 cubic inches. Allowing 5 minutes for trial cuts and skimming the ends true the time taken for turning will be

$$15 + \frac{270}{3} + 5 = 110 \text{ minutes.}$$

This will be worth 7/4. The total cost to this stage will be 16/6 + 7/4 = 23/10. It follows that the 2/8 saved in the early stages would be more than offset by the extra turning. But if the bar were turned on a heavy turret lathe of, say, 8 h.p., the machining would take only about 50 minutes. And if the larger machine were rated at 6/- an hour the cost of turning would be only 5/-. This added to 16/6, the cost of the material, gives a total cost of 21/6, which is less than by the forging method.

These figures, taking no account of preparation time and fatigue, are scarcely conclusive, yet are not misleading. Neither has the value of the swarf been reckoned. At 0·08d. per lb., for instance, the extra swarf from the bar would be worth nearly 5d. and this would be of further advantage to the bar method. It must not be forgotten, however, that the swarf would have to be collected from the machine and carted to the dump for either method.

There would be one difference in the shafts rough

turned in the three ways which have been described; the one turned from bar on the weak lathe would probably run nearly true on its centres; the forged shaft would probably be true at the ends but be bent so as to run out near the centre; the one made from bar on the turret lathe would almost certainly be bent near the collar through having to reverse it in the chuck and probably it would have minor bends elsewhere. Straightening the last would take about 3 minutes and the one from the forging $1\frac{1}{2}$ minutes. The alternative to this would be to leave about $\frac{1}{16}$ inch on the diameter for semi-finishing.

Up to this stage the study has been diverted by many side issues. The finishing shall be direct as an indication that the whole study can be brief. To save altering the steady several times and to minimize speed, feed and tool changing it will be better to exchange the shafts between the centres as they reach convenient stages.

	Mins.
Semi-finishing—	
Straighten	1·5
Adjust steady (once for 3 shafts)	1·0
Load (twice)	2·0
Set tool (4 times)	4·0
Gauge	2·0
Turn $(48 + 1 + 12 + 1)\ \frac{62 \times 16}{160}$	6·2
Turn $(24 + 1 + \frac{1}{2} + 1)\ \frac{26\frac{1}{2} \times 16}{114}$	3·7
Turn sides of collar $\frac{2 \times 1\frac{1}{2} \times 64}{114}$ (hand feed)	1·7
Total	22·1
Finishing—	
Steady (for safety)	1·0
Load	2·0
Set tool	1·0
Gauge	3·0
Turn $(14 + 1 + 10 + 1 + 12 + 1)\ \frac{39 \times 32}{220}$	5·7
Skim sides of collar $\frac{2 \times 1 \times 64}{220}$	0·6
Chamfer ends with file	1·0
Total	14·3

The total time for the 3 shafts amounts to—

	Mins.
Preliminary and roughing . .	183·0
Semi-finishing	66·3
Finishing	42·9
Total . . .	292·2

There are still to be reckoned changing speeds and feeds, exchanging chuck for face plate, etc., but these may be held to be sufficiently allowed for in a $12\frac{1}{2}\%$ fatigue allowance. If the operator is to earn time and a quarter the time allowance will be—

	Mins.
FFT	292·2
$12\frac{1}{2}\%$ *fatigue* . . .	36·5
Preparation . . .	30·0
	358·7
25% P.W. . . .	89·7
	448·4

In practice the man would be given 450 minutes.

Tool grinding or replacement can be attended to during the cut if shop facilities are well arranged. In old-fashioned works turners often have a hundredweight or two of turning tools, most of them scarcely usable. In other works the opposite extreme is in vogue, the turner being allowed to possess no stock of tools and not allowed to grind any. It is far better for him to have a small selection, with duplicates where convenient, and to do his own minor resharpening on a wheel near his machine.

The fatigue allowance should vary with circumstances. If there were only one shaft to do, the tool, steady and other changes would be proportionately increased, adding considerably to the physical strain. Besides this there would be more mental strain. An allowance of $12\frac{1}{2}\%$ would be ample if the man were familiar with the job or others nearly like it, especially since tool changes are

allowed for, but not with only one shaft to do, in spite of the 30 minutes' preparation time. If it were known that the assumed speeds and feeds were actually available on the machine selected for the job, 15% would be a reasonable fatigue plus tool and contingency allowance. If the capabilities of the machine were not definitely known 20% would be fair.

If the machine were employed exclusively on shafts the 30 minutes' preparation time could be reduced to 15 minutes and the fatigue allowance to 10% if long cuts were the rule. With more intensive production a 15% fatigue allowance might be given but the turner would have to work two or more machines simultaneously.

In intensive production multi-tool centre lathes are largely used, principally on shafts where there are plenty of shoulders. The calculations follow exactly the same lines as in the last example. It is necessary to study the machine as well as the job to ascertain how the tools may be applied. The only points to note are—

Feeds and speeds are less, mainly to prevent frequent regrindings of the tools and resetting them, but also because more rapid cutting would absorb too much power or spring the work.

The cutting time is usually that taken by the tool which cuts the longest shoulder. The r.p.m. are determined by the largest diameter being cut, subject to the restriction first mentioned. In this connexion it is worth mentioning that the cemented tungsten carbide tipped tools are often helpful, since they can be used on large diameters at a high speed, while high speed steel tools are working on less diameters at the speeds which suit them.

For instance, in Fig. 20 carbide tipped tools at C and D enable the cutting speed on diameter A to be suitable for the high speed steel tool which turns it. Without the carbide tools the speed would have to suit the flange diameter. It does not follow that the speed could be

further increased by applying carbide at A, for that cutting material has its limitations; moreover the total volume of material removed per minute is dependent upon the power. The nature of the drive on the component also has to be considered. If there are holes, or lugs as

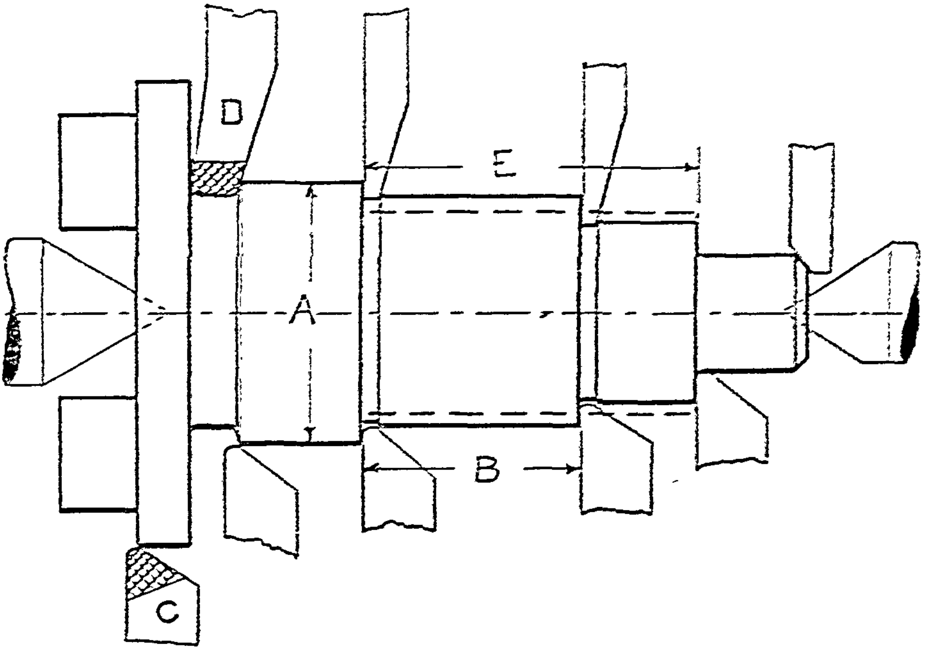


FIG. 20. AUTOMATIC CENTRE LATHE WORK

indicated in Fig. 20, a reliable positive drive can be obtained.

The time of the turning cut is dependent on the length B of the longest shoulder. If one shoulder were removed, as indicated by the dotted lines, the time would be increased by the difference between B and E although the amount of work to do would be lessened. Often the grooving tools would be better employed after the turning had been finished. In that case the cutting time would be the turning time plus the grooving time. For further remarks on multi-tooling see pages 130, 134 and 139.

When screwing vee threads with single point tools and

chasers the number of cuts or passes is given (using the nearest round numbers) by—

$$\frac{64}{\text{T.P.I.}} \text{ for external use.}$$

$$\frac{80}{\text{T.P.I.}} \text{ for internal threads.}$$

If a specially good finish is desired on steel, allow 3 passes extra for fine and 6 passes extra for threads coarser than 10 per inch.

Thus to cut a male thread $\frac{1}{16}$ inch pitch, the number of passes will be $\frac{64}{16} = 4$. And an internal thread $\frac{1}{4}$ inch pitch will require 20 passes. Speeds may be much higher than are frequently used.

TABLE XXV

SCREWING SPEEDS WITH CHASERS

	(*Feet per Minute*)			
	Mild Steel	Tough Steel	Brass	Cast Iron
Straight through threads . . .	60	30	100	30
Screwing to a shoulder	40	30	40	30

To the nominal screwed length about $\frac{1}{4}$ inch or 2 threads, whichever is the greater, must be added to obtain the length of the pass. For straight through threads add a further $\frac{1}{8}$ inch for overrun at the finishing end.

The time in seconds for each pass will be—

$$\frac{\text{Length of pass in inches} \times \text{T.P.I.} \times 60}{\text{R.p.m.}} \text{ seconds.}$$

Manipulating time will be about 9 seconds per pass for short easy threads, 12 seconds for odd threads or where

engagement with lead screw is not perfectly simple, and more, according to circumstances, for difficult cases. The 9 seconds is made up of—

Withdrawing tool and winding saddle back .	3 sec. + 1 sec. for each 4 in. length screwed
Resetting tool to correct depth . . .	3 sec.
Re-engaging nut with lead screw . . .	2 sec.

It will be obvious from the above particulars how to modify the constituents to suit other cases and how to arrive at the overall time for cutting a thread. It should be observed that the above data are suitable only for repetition work done most skilfully. But the addition of 50% to the overall screwing time found by using them will be just about what to expect under ordinary conditions, as in the tool room, for instance, where screwing is not a man's regular occupation.

The turner will need some allowance for gauging the screw when he has cut it. About ½ minute will cover ordinary cases. Very long screws or screws of large diameter must be considered and the time allowed as seems reasonable. There are too many variables for a useful rule to be formulated.

Capstan and turret lathe work may be divided into bar and chuck work. Most of the data given for centre lathes apply. In general, speeds and feeds are slightly less. This is partly to save too frequent re-sharpening, and partly through multi-cutting, which increases the load on work and machine. Of course if metal is cut dry on a centre lathe and flooded with cutting compound on a turret lathe, the speed can be higher on the latter. Here it is always assumed that those metals requiring suds for efficient cutting are flooded with them. Most turret lathes are used too much like centre lathes. They are inadequately equipped and badly supervised.

Estimates may safely be based on the cutting speeds

TABLE XXVI

Turret Lathes, Speeds, and Feeds for Box Tools

Dia. of Bar	Mild Steel			Tough Steel			Brass		
	Feed per Rev.	$\frac{1}{16}$ in. Chip 110 F.p.m.	$\frac{1}{4}$ in. Chip 90 F.p.m.	Feed per Rev.	$\frac{1}{16}$ in. Chip 80 F.p.m.	$\frac{1}{4}$ in. Chip 60 F.p.m.	Feed per Rev.	$\frac{1}{16}$ in. Chip 200 F.p.m.	$\frac{1}{4}$ in. Chip 180 F.p.m.
		R.p.m.	R.p.m.		R.p.m.	R.p.m.		R.p.m.	R.p.m.
$\frac{1}{8}$	·002	3,300		·002	2,400		·003	6,000	
$\frac{3}{16}$	·003	2,200		·003	1,600		·004	4,000	
$\frac{1}{4}$	·004	1,600		·004	1,200		·005	3,000	
$\frac{3}{8}$	·005	1,100		·004	814		·006	2,000	
$\frac{1}{2}$	·006	840	688	·005	611	458	·008	1,500	1,300
$\frac{3}{4}$	·007	560	458	·006	407	306	·010	1,000	916
1	·008	420	344	·007	306	229	·011	764	688
$1\frac{1}{4}$	·009	336	275	·007	244	183	·012	611	550
$1\frac{1}{2}$	·010	280	229	·008	204	153	·014	509	458
2	·012	210	172	·009	153	114	·016	382	344
$2\frac{1}{2}$	·015	168	137	·012	122	92	·018	306	275
3	·020	140	115	·015	102	76	·024	254	229

The above feeds give a first-class finish. They may be increased by 50% for many purposes.

given in Tables XXIII and XXVI. The feeds for chuck work, subject to the range available, and when not more than 2 tools are cutting simultaneously, can be the same as for centre lathe work. With 3 tools the feed rate might have to be reduced to $\frac{2}{3}$ of the possibilities with 2 tools, to $\frac{1}{2}$ with 4 tools, and so on in proportion. But the depth of cut and the speed affect results. Some tools will be cutting large and some small diameters. The latter will absorb power in proportion to their lower speed, depth of cut being the same. Obviously a reliable estimate cannot be made until the whole of the facts are known. For preliminary estimates it will be advisable to assume a feed not exceeding 0·010 inch per revolution for light machines (those which will take $1\frac{1}{2}$ inch diameter bar and swing about 12 inch diameter), 0·015 inch for medium machines, and 0·030 inch for machines which will take a 4 inch diameter bar or swing about 24 inch diameter.

It will be noted that the speeds in Table XXVI are based on the outside diameter of the bar; so the speed at the point of the tool is, as a rule, considerably less. For small bars of free cutting material the r.p.m. can be increased if the machine permit. More often a lower speed has to be used. The feeds, too, cannot always be exactly obtained. As a rule there are several tools applied during a capstan operation and the feeds and speed have to be adapted to suit the whole of the circumstances. The speeds and feeds for $\frac{1}{16}$ inch chip (i.e. $\frac{1}{8}$ inch reduction in diameter) may be used for shallower cuts; similarly any cut over $\frac{1}{16}$ inch deep may have the speeds and feeds given for the $\frac{1}{4}$ inch chip. In the average workshop form tools are resorted to too easily. With a little thought (perhaps, if necessary, a small modification to the design of the components) it is usually possible to produce the desired shape by copying or generating. The first cost of the apparatus will be far greater than form tools, but afterwards maintenance will be much less and the results more accurate and uniform. The practice of generating

with single-point tools should be widely extended for castings and forgings. On bar work it is generally more convenient to use form tools.

When form tools are used the surface speed of the work at the commencement of the cut should never exceed the figures given in Table II. An exception may be made for parting tools under favourable conditions, particularly when they commence their cut on a surface free from scale, if a definite gain in time results thereby. Feeds for parting tools from $\frac{1}{16}$ inch wide upwards may be as shown for the corresponding form tools in Table XXVII.

TABLE XXVII

FEEDS FOR FORMING TOOLS

Width of form—	$\frac{1}{16}''$	$\frac{3}{32}''$	$\frac{1}{8}''$	$\frac{3}{16}''$	$\frac{1}{4}''$	$\frac{3}{8}''$	$\frac{1}{2}''$	$\frac{3}{4}''$
Feed per rev.—								
Steel	·001	·0015	·0025	·0025	·002	·0015	·0012	·001
Brass	·0015	·0025	·003	·003	·0025	·002	·002	·0015

Width of form—	1"	2"	3"
Feed per rev.—			
Steel	·001	·001	·001
Brass	·0012	·001	·001

The above may usually be taken as the maximum feeds for simple well supported work. Parting tools can be forced 50% more rapidly, but this shortens their life and leaves the parted faces rough. The shape formed and the position and diameter of the smallest neck affect the amount of feed which can be used. As a rough guide, if the smallest neck is near the collet the feed must be reduced by 25% if the diameter of the neck is half the width formed, and by 50% if this diameter is one-fourth of the width formed. Wide or intricate forming is generally done at slow speed to prevent chatter and to prolong the life of the tools, sometimes at half the normal speed or even much less.

These restrictions do not apply to parting tools, because the governing relation does not exist until their work is practically done. With hand feeding there is usually a more rapid feed at the start than when the neck is nearly to size. The same effect is partially obtained on cam operated feeds through the roller action over the peak of the cam as described on page 137.

If special cams are used more can be made of this than is usually the case. On the other hand, since the edge which forms the neck has the most work to do and dulls first, it would be unwise to accelerate its failure by much forcing.

TABLE XXVIII

DATA FOR COLLET CHUCKS—HAND-OPERATED

Feed Bar to Stop—

⅝ in. dia. (and smaller) bars	2 sec.
1¼ in. dia. ,,	3 ,,
2 in. dia. ,,	5 ,,
3 in. dia. ,,	20 ,,
4 in. dia. ,,	30 ,,

Components whose length exceeds a few inches need more time.

Inserting Fresh Bars—

¾ in. dia. (and smaller) bars	1½ min.
1⅝ in. dia. bars	2 ,,
2 in. ,,	3 ,,
over 2 in. ,,	4 ,,

These figures apply to average conditions with bars 12 feet long. Some transport is generally necessary, the bars having to be carried a few yards. Often there is waste of time through having to carry the bars a long distance. An examination of the bar feed mechanism in many works will show that this is incomplete, parts having been mislaid, and bars are pulled or pushed through by hand.

Holding Second Operation Work in Collet. Allow 3 seconds for small, 5 for medium and 8 seconds for large components. The time depends on the weight and shape of the component and the amount of reaching over the

machine to insert it. Double the above times if the chuc
will not automatically true the component.

TABLE XXIX

DATA FOR TURRET LATHE MANIPULATION

Sliding and Indexing Turret—

$\frac{3}{4}$ in. machine	2 sec.
$1\frac{1}{2}$ in. ,,	3 ,,
2 in. ,,	5 ,,
3 in. ,,	10 ,,
4 in. ,,	15 ,,

Double these times when the work is unusually long.

A 2-inch machine means one which will take as
maximum a 2-inch diameter bar, or a chucking machin
of the same size.

Tool Post Sliding—

1 sec. for small lever-actuated slides
3 sec. for small screw-actuated slides
5 sec. for medium screw-actuated slides
10 sec. for large screw-actuated slides

These are for simple straight sliding. If the saddle ha
also to be moved longitudinally allow extra time b
judgment. In intensive production longitudinal saddl
movement is avoided as much as possible. Far too muc
compound movement is tolerated in general work.

Indexing Square Tool Post. Allow 5 seconds for small,
7 for medium, and 10 seconds for large machines. Thes
times are extra to sliding.

Changing Speed or Feed. Allow 3, 5 or 8 second
according to the size of the machine. In a cycle th
number of changes is never one. If there is a change o
feeds, for instance, it must be brought back to the origina
to start the next component.

Screwing on Turret Lathes. For tapping refer to th
data given in Chapter III. Screw cutting with chase
held in tool post is the same as already given for centr
lathes. Chasing on brass lathes is also the same except
that manipulating time is reduced to 3 seconds per pass.

Screwing with dies is of two kinds: with button dies
and with self-opening die heads.

In either case suitable screwing speeds are as follows—

TABLE XXX

DATA FOR SCREWING WITH DIES

Material	Feet per Min. Screwing Speed
Free cutting mild steel (over 8 T.P.I.)	40
Ordinary mild steel (8 T.P.I. and coarser)	20
,, ,, (over 12 T.P.I.)	30
,, ,, (12 T.P.I. and coarser)	25
Brass (over 8 T.P.I.)	150
,, (8 T.P.I. and coarser)	100
Tough steel, pipes	15
Black bars	15
Cast iron	25

The above are maximum speeds for favourable conditions.

One pass suffices for excellent work when dies are in good order and threads are not coarser than 8 T.P.I. A good deal depends on the nature of the material, but it is generally best to assume two passes for less than 8 T.P.I. The length of the pass for a screw of length L inch full thread will be $(L + \frac{1}{4})$ inch. Although not quite correct for all pitches, this will be found near enough for ordinary time calculations.

The time per pass is evidently

$$\frac{(L + \frac{1}{4}) \times \text{T.P.I.} \times 60}{\text{R.p.m.}} \text{ seconds.}$$

For self-opening dies the return is included in the sliding and indexing movement, but 2 seconds' allowance for resetting the die head is necessary, unless that can be done during the progress of an earlier cut.

Button dies have to take a forward and a reverse pass. Between the two there is a dwell for reversal. This reversal is made twice per cycle, and 5 seconds per cycle is a reasonable time to allow. The time for the forward pass is the same as for self-opening dies. The reverse pass is usually made at a higher speed. Failing accurate

knowledge of the conditions the reverse may be assumed to take $\frac{2}{3}$ of the time of the screwing pass.

Gauging is intermittent when dies are used. One in four is a reasonable average to gauge.

When several tools in a group cut simultaneously the tool allowance may be expressed as a percentage of the actual cutting time of the group. A suitable amount is $2\frac{1}{2}\%$ of the cutting time for each of the tools in action together, tools with comparatively light duty being ignored. For instance, if the cutting time of a group of tools is 7 minutes, and there are 5 tools in the group of which one, being in action for only a small part of the time, can be ignored, the tool allowance will be $4 \times 2\frac{1}{2} = 10\% = 0{\cdot}70$ minutes.

This rule is satisfactory when speeds and feeds are such that each tool will stand about 2 or 3 hours actual cutting before requiring re-sharpening.

Fatigue time is extra. It may be $7\frac{1}{2}\%$ of the FFT where there is plenty of opportunity to rest during cutting—not less than 2 minute spells—and 10% otherwise. For ordinary single tool turning 15% of the FFT covers fatigue, minor constituents and tool attention. Very intricate or fine work which needs continuous attention on the part of the turners should have a 25% allowance.

The fatigue allowance for small capstan lathes which have no power feed should be 15% when, as is usual in that case, all tool attention is given by a setter, and no tool allowance is required by the operator who can rest while the setter is at work.

It should be understood that the percentage tool allowance for groups of tools applies to the whole cutting time. A turret lathe may employ several groups of tools, each group cutting in its turn. The allowance, being based on the average group, naturally applies to all the groups. If the whole cutting time for an operation were 4 minutes and the cutting time of the average group were one

minute the allowance would be 0·4 minutes (not 0·1 minute) if 10% were the tool allowance.

Setting up for an operation on a turret lathe may be rated at 20 minutes plus 4 minutes, 20 + 5, 30 + 5 or 30 + 6 minutes, the first figure being for general preparation and the second being multiplied by the number of tools to give the total tool setting time. The grading of machines is according to their accessibility and massiveness.

Thus a capstan which will take a 2-inch diameter bar as a maximum would be in the second grade. If 8 cutting tools were set up for an operation, the setting up time would be rated at $(20 + 8 \times 5)$ minutes = 60 minutes. Naturally, such a rule can be only a rough guide. The kind of tool, the accuracy required and the shop facilities all have an effect on the setting up time. So do the previous set-up on the same machine and whether "set-up" charts are made and referred to or not. A "set-up" chart of quite a rough character will save 20% of the above times when associated with a good tool service.

Automatic turret machines require about 25% more than the above times when "set-up" charts are available, about 50% more when memory is depended on, and 100% more for the first set-up. But each type of auto. has to be studied for accurate estimating; some are very inaccessible; in some camming is simple, in others changing cams provides work for several hours. Still, the rule will be found a useful guide for average cases.

An automatic turning machine is only the ordinary turret or multi-cutting centre lathe provided with cams to replace (partially) the operator. It is important to keep autos. running with as few stoppages as possible. If they stop frequently they will not be an economic success. For this reason cutting tools should have light duty individually. But multi-cutting will raise operation efficiency to a very high level when well arranged.

For any particular job the range of available speeds

and feeds on an auto. is far more restricted than on a hand operated machine. The machine must be studied before an accurate estimate can be prepared, whereas general data will usually suffice for calculating fairly nearly what a hand operated machine will perform.

The constituents for work on single spindle autos. are—

(*a*) Feeding to stop (including an allowance for inserting new bars) or chucking. Most of the work connected with inserting new bars can be done while the machine is running.

(*b*) Indexing and sliding.

(*c*) Cutting.

(*d*) Fatigue, tools, etc.

The data given for turret lathes apply generally, but feeding to stop on autos. is done in about 50% of the time in Table XXVIII. Indexing and sliding occupies from ½ to 30 seconds, according to size and type of machine, for each face. When a face is slipped the sliding is eliminated on some machines; in others the full motion is gone through for every face, idle or not. Corss-slide tools work, as far as possible, simultaneously with turret tools. On some machines the standard rate of feed on the cross-slide is half that on the turret, and this must not be overlooked if the cross-slide facing is wider than half the length which is simultaneously turned.

Cutting off must be the last movement in the case of bar work. Some of the parting can be during other cuts, as a rule, but how much depends on how heavy they are.

The automatic feed imparted by rollers working on cams is often very much slowed down at the peak of the cams. This effect is inappreciable on most plate or edge cams and sometimes on drum cams. It depends on the slope of the cam.

Fig. 21 indicates at A a roller being urged by a drum cam in direction E by the cam moving in the direction shown by arrow F. At B the cam has moved through distance G and forced the roller the distance H. When,

as at C, the cam has moved another space equal to G the roller has been forced through I, which is less than H. The next position of the cam shown at D, where it has again moved through a distance equal to G, has only moved the roller through J. After that further movement of the cam permits the roller to dwell.

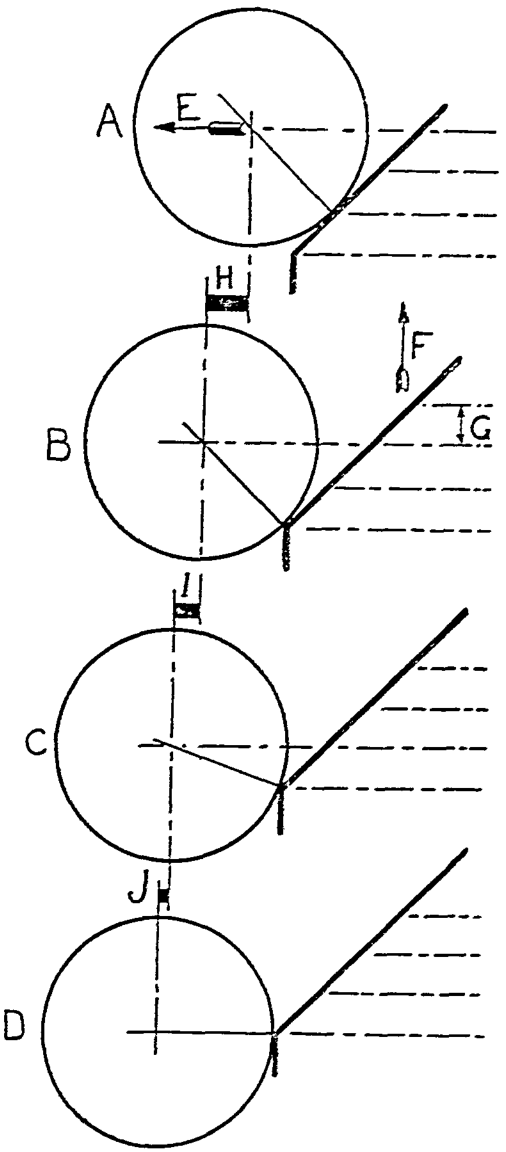


Fig. 21. The Retard

Obviously the slowing down depends on the angle of the cam and the size of the roller. The effect is accentuated by the corner of the cam being radiused. Since there is often more cutting to be done at the end of the cutting stroke (on meeting a shoulder of extra material), or it is desirable to end with a fine feed to obtain a good finish on a face, the retard is often necessary. But it exists, whether necessary or not, and must be allowed for.

On automatic lathes the withdrawal of the tools from the work, the indexing (if any), and the approach to the work are made at a fast rate. The slow feed begins from just before the cut

commences and lasts to the end of the cut. When a hole is drilled or bored quite through a component the fast rate can be tripped in immediately the drill has cleared, before the peak of the cams is reached by the roller, if, and only if, any other tools which are engaged at the same time also have a clear over-run. In this way the time lost through the retard can be saved; but this or equivalent opportunities seldom occur.

The practical way of allowing for the retard is to add to the nominal length of stroke required an amount determined by a study of the machine. For small automatic chucking lathes $\frac{1}{4}$ inch or $\frac{1}{2}$ inch is often about right. That is, if the nominal stroke allowed to the turret while boring a hole $1\frac{1}{2}$ inches deep were $1\frac{3}{4}$ inches the time calculation should be based on $2\frac{1}{4}$ inches because of the retard. Evidently this method fails for very short cutting strokes because the retard has commenced before the stroke begins. For example, if a solitary tool were to face a shoulder, being required to cut actually through a distance of $\frac{1}{16}$ inch it might be set to commence the fine feed $\frac{1}{16}$ inch before beginning to cut; that is the cam has to advance it only $\frac{1}{8}$ inch before the end of the stroke is attained. In that case about $\frac{1}{4}$ inch addition to the nominal stroke would perhaps be right as the basis for the time calculation. However, the real rate of feed at that part of the cam might be only $\frac{1}{3}$ of the nominal rate before the roller reached the peak; hence, the tool being solitary, the nominal rate would be increased so as to bring the real rate right. When that is done the $\frac{1}{4}$ inch allowance for retard is not required. Evidently a great deal of time can be wasted on automatics if the camming and setting up is not well done. Unless the man responsible in the shops is known to be a qualified geometrician he should always be given the assistance of a draughtsman for working out cams. Each class of machine requires special study, and deserves it.

The constituents for multi-spindle autos. differ a little

from those for single spindle machines. In the case of chuck work the loading and unloading takes place at a special station during the cut by the tools at other stations. Constituents (*b*), (*c*) and (*d*) (page 136) remain. The FFT is the cutting time (which is that of the longest cut) plus indexing time. For bar work the constituents consist of (*b*), (*c*) and (*d*) plus the allowance for inserting fresh bars.

When one man looks after several machines the ordinary fatigue and tool allowance needs supplementing; there will be times when two or more machines require his attention together. Further, automatics are usually set up by men of high skill and fed by others—youths, perhaps. During setting time the youth cannot produce on the stopped machine. The amount to allow for the stoppages depends very much on the length of the runs which the machines can make with unchanged set-ups. For moderately long runs where the machines are not forced a 10% contingency allowance besides the fatigue and tool allowance given on page 134 is reasonable. For average conditions, where quantities of a few hundreds at a time are dealt with, a 20% addition is likely to be required.

Setters are paid in various ways, e.g. at day-rate plus a bonus on the number of parts done in their section or by piece-work based on the amount of setting they do. Probably the best way is to pay them according to the output they, with their helpers, obtain.

If a setter can attend to 8 machines and the basic time for the components being made on them is *a*, *b*, *c*, etc., his piece-work price can fairly be based on $\frac{a}{8}$, $\frac{b}{8}$, $\frac{c}{8}$, etc. He will need no special setting time, for the above include that. The contingency allowance therein may be 10% when the setter looks after 8 machines and 20% when he can only manage to maintain 4 machines. Similarly

with the helper who can feed 4 machines: his piece-work allowance or price may be based on $\frac{a}{4}, \frac{b}{4}$, etc.

Thus for automatics there will be for a given operation:

Cycle time	=	Floor to floor time + bar feeding allowance.
Operation time	=	Cycle time plus fatigue and tool allowance.
Basic time	=	Operation time plus contingency allowance.
Piece-work time	=	$\frac{\text{Basic time} + 25\% \text{ (or as agreed.)}}{\text{No. of machines attended.}}$
Piece-work price	=	Piece-work time × basic rate.

When a man (engaged with one component) simultaneously works, say, three consecutive operations on three machines, and the operation times are unequal, his basic time for all three must be that of the slowest operation, for that determines his output.

Occasionally it is desirable to make a diagram to analyse the possibilities of multi-machine working. Such a diagram is shown in Fig. 22 for operations A, B and C. Commencing with A there is first of all the loading (including unloading) and other machine attention time (shown hatched). The cutting time is shewn in black. Attention to B may commence 5 seconds or so (according to circumstances) after the cutting of A starts. 50 seconds later the operator is free to turn to C. This walk to C takes, say, 5 seconds. After doing what is necessary there he goes back to A. This is not an efficient arrangement as regards output per machine for there are long periods, shown blank, during which the machines for B and C are doing nothing.

Nevertheless it may be an economical way of doing the work. In 3 minutes one operator does what by single machine working would take 7⅝ minutes. When overhead charges are reckoned as shown in Chapter XI, the real gain may be far less than appears from a consideration of the wages only—it may become negative and result in increased cost. The possible remedies are obvious.

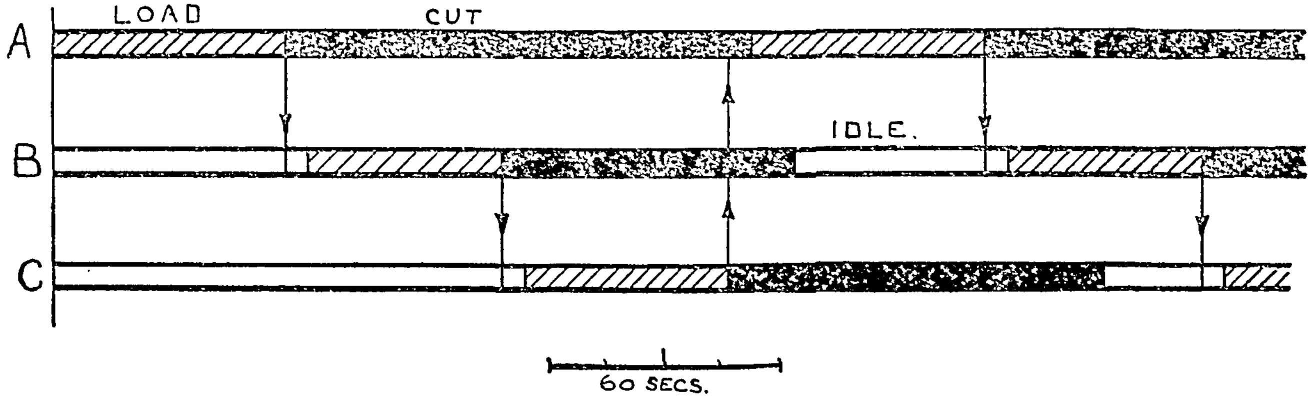


FIG. 22. MULTI-MACHINE OPERATING

Multi-machine working has for its opposite *Group* or *Gang Working* and *Group Piece-Work Pay*. In group piece-work a number of operators work at a process for which a price or time is fixed, and all share the gain in proportion to the time they work and their basic rates of pay. It is better avoided if possible. The individual incentive is lacking and experiments show that individual output may be increased from 15 to 20% by reverting from group to individual piece-work. It has the advantage

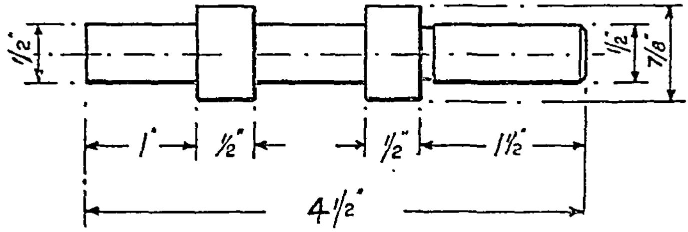


FIG. 23. MULTI-SPINDLE AUTO. COMPONENT

of simplifying book-keeping, fewer clerks are necessary where it is in vogue, and for some collective processes no other method is suitable: e.g. erecting structural work, navvying, and some kinds of line production.

When sufficient data have been accumulated it is easy to make simplifications and generalizations which are suitable for rate fixers to use. Cutting time is easy to calculate. Loading time may quickly be estimated if it be not already known. There remain manipulating and the fatigue and other allowances. Provided the figures used have been prepared in accordance with the known data there is no harm in including the manipulating with the other allowances as a percentage of the cutting time. But the results will be wide of the fair basic time unless the percentage is varied with each different class and size of component. It will be found far better to make approximate estimates as shown in the following examples.

In Fig. 23 is depicted a component which it is required to machine on a 4 spindle bar auto. The material is tough steel. To find the FFT it is not necessary to go

into great detail. The job is a simple one which any 4 spindle auto. which will take a $\frac{7}{8}$ inch diameter bar can easily do.

The FFT will be the time of the longest cut + indexing time.

Which will be the longest cut?

From Table XXVI the suitable speed will be about 270 r.p.m. for turning the $\frac{1}{2}$ inch diameter and for forming.

The nominal length of $1\frac{1}{2}$ inches requires $\frac{1}{4}$ inch adding for starting the cutting feed before the tool reaches the bar and for the retard at the peak of the cam. If one were sure of the details of the machine it might be possible to reduce this $\frac{1}{4}$ inch to $\frac{1}{8}$ inch. On the other hand it might have to be increased. However, with the ·006 inch feed given in Table XXVI the time for the cut will be

$$\frac{1\frac{3}{4} \times 166}{270} \text{ minutes} = 1{\cdot}08 \text{ minutes (nearly).}$$

The forming cut has a nominal depth of

$$\frac{\frac{7}{8} - \frac{1}{2}}{2} = \frac{3}{16} \text{ inch.}$$

Now a forming tool always has a fine feed. It is most necessary to set it so as to economize its movement as much as possible. $\frac{1}{32}$ inch is a safe distance from the bar on a machine of this class for the fine feed to commence. At the end of the cut there will be a slight dwell to release the spring of the machine. $\frac{1}{16}$ inch added to the $\frac{3}{16}$ inch nominal depth will therefore be about right. The total width of the forming cut is 2 inches. By Table XXVII the normal feed for a tool 2 inches wide is 0·001 inch; but since the diameter $\frac{1}{2}$ inch is only $\frac{1}{4}$ of this width the real feed must be only 0·0005 inch (page 131).

The time will be

$$\frac{\frac{1}{4} \times 2000}{270} = 1{\cdot}85 \text{ minutes.}$$

The indexing time for the machine is 5 seconds.

Hence the FFT = 1·94 minutes.

The component is rather long—new bars will often have to be fed, but most of the work can be done while the machine is running, hence the true cycle time could be safely fixed at 2 minutes. Four tools rank for tool allowance (2 turning, 1 forming, 1 parting) making it 10%. Fatigue also equals 10%. Quantities being not large a

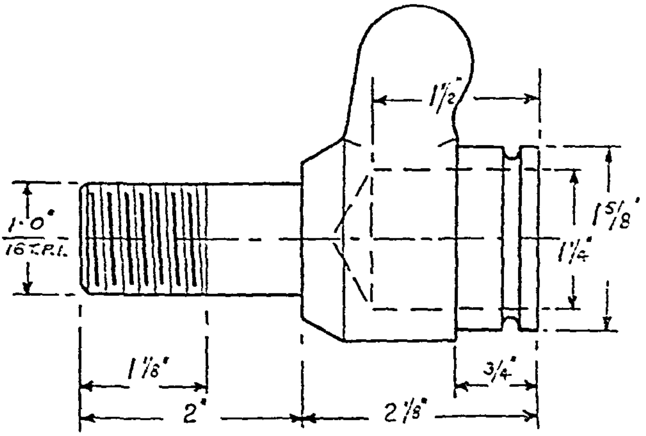


FIG. 24. AN EXAMPLE OF CAPSTAN WORK

supplementary or contingency allowance of 20% is also required. Then, if a man feeds 4 machines his basic time will be

$$\frac{2 + 40\% \text{ of } 2}{4} \text{ minutes} = 0{\cdot}7 \text{ minutes.}$$

And his piece bonus time to enable him to earn time and a quarter will be 0·88 minute.

The component shown in Fig. 24 is to be machined in a powerful capstan lathe. Mild steel drop forgings are supplied in batches of 500. A rough estimate of the capstan time is required.

For the first operation chuck by the largest boss, because that is to be left rough yet correctly placed in relation to the machined surfaces.

If the large end were machined first a jaw chuck would have to be used for the second operation. A collet chuck is quicker, so the stem should be turned first.

1st Operation—

Load, etc. (jaw chuck)		30 sec.
Rough and finish turn 1 in. diameter $\dfrac{2\frac{1}{4} \times 80 \times 60}{340} \times 2$ . . .		64 ,,
Rough and finish face shoulder and end (before finish turning) $\dfrac{\frac{5}{8} \times 80 \times 60 \times 2}{220}$ . . .		27 sec.
Screw $1\frac{1}{8}$ in. along $\dfrac{1\frac{3}{8} \times 16 \times 60}{100}$ . . .		13 ,,
Handling: Turret	$4 \times 3 = 12$	
Tool post	$2 \times 4 = 8$	
Change speed	$5 \times 3 = 15$	
Gauge	$= 5$	
	40 . .	40 ,,
		174 sec.

2nd Operation—

Load, etc. (collet chuck).		5 sec.
Centre to start drill time . . .		10 ,,
Rough face end $\dfrac{\frac{1}{2} \times 80 \times 60}{220}$ . . .		11 ,,
Drill $1\frac{1}{2}$ in. deep and rough turn $1\frac{5}{8}$ in. dia. $\dfrac{1\frac{3}{4} \times 80 \times 60}{220}$.		38 ,,
Finish turn $1\frac{5}{8}$ in. dia. $\dfrac{1 \times 80 \times 60}{220}$.		22 ,,
Finish face end, Groove $\frac{4}{32}$ in. deep $\dfrac{\frac{5}{32} \times 400 \times 60}{220} = 17$		25 ,,
Handling: Turret	$4 \times 3 = 12$ . .	22 ,,
Tool post	$2 \times 3 = 6$ . .	133 sec.
Gauge	$= 4$	
	22	174 ,,
Total capstan time . .		307 ,,

For practical purposes both operations consist of single tool turning, hence 15% will cover fatigue and tools. This brings the basic time to 353 seconds or 5·9 minutes. This speed could be maintained only in intensively worked shops. The average works would require 7 minutes.

A few comments on the second operation are desirable: the finish turning is done separately to prevent irregularities which other cuts might cause if taken simultaneously. Drilling and rough turning may proceed together if the machine is powerful enough. It is in this case known to be, and the chosen speeds and feeds are what the machine will give. About $2\frac{3}{4}$ h.p. is necessary and the machine is driven from a 12 inch pulley, running at 200 r.p.m. with a belt 4 inches wide. Hence the available power is $\frac{12 \times 200}{3600} \times 4 = 2{\cdot}7$ h.p. The tools should be arranged in the front and rear posts so that the saddle is not moved along the bed. Once the saddle is shifted conditions approaching centre lathe turning are approached, more skill is needed and the time is increased.

As already stated, accurate time estimates for automatic turning cannot be made without exact knowledge of the machines to be used. Nevertheless it is not difficult to form a fair idea without going into great detail. As an example the brass pin in Fig. 25 is to be turned on an automatic machine from $\frac{5}{16}$ inch diameter bar. The machine has (one must assume some knowledge of it) a slide for turning or drilling, a forming slide, and a parting off slide, the two latter being combined so that they cannot be used together. What is the probable floor-to-floor time, neglecting bar feeding etc.?

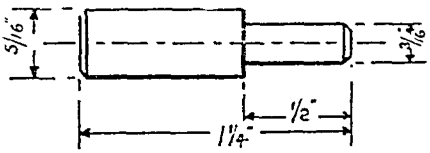


Fig. 25. Turning a Brass Component. Single-spindle Auto. Work

Table XXVI shows 2500 r.p.m. and 0·0055 inch feed for a brass bar of this size, but it might be better with suitable quality bar, to run at a higher speed and a finer feed to get a good finish with one cut. There is no nice forming or intricate work, so that would be quite practical. However, let 2500 r.p.m. and 0·0055 inch feed be decided on.

With work of this kind allowance for clearances, excess material, and so on can be made very small—bars are sure to be close to size and parting off precise. The nominal $\frac{1}{2}$ inch length need have only $\frac{1}{32}$ inch added for the approach.

A.	Feed and return slides	$= 0{\cdot}5$ sec.
B.	Turn $\frac{17}{32} \times \dfrac{10000 \times 60}{2500 \times 55}$	$= 2{\cdot}3$,,
C.	Form neck to $\frac{3}{16}$ in. dia. ready for parting off, chamfer back edge	$= 0{\cdot}0$,,
D.	Part off $\dfrac{\frac{1}{8} \times 400 \times 60}{2500}$	$= 1{\cdot}2$,,
	Total	$= 4{\cdot}0$ sec.

C takes place during B and leaves a $\frac{3}{16}$ inch neck at back but the parting tool at D has to travel just past the centre to remove the pip—it is also slightly inclined, of course, at the edge, hence $\frac{1}{8}$ inch instead of $\frac{3}{32}$ inch travel for that tool. Actually bar feeding can take place during A. The next example, Fig. 26, is to be made from $\frac{3}{16}$ inch diameter bar on a single spindle auto. provided with a six-face turret and rear and front cross slides. The material is mild steel.

A.	Feed	$= 0{\cdot}5$ sec.
B.	Turn $\dfrac{\frac{11}{16} \times 333 \times 60}{2200}$	$= 6{\cdot}25$,,
C.	Form head to $\frac{3}{32}$ in. dia. $= \dfrac{\frac{1}{8} \times 500 \times 60}{2200}$	$= 1{\cdot}7$,,
D.	Centre end	$= 0{\cdot}0$,,
E.	Drill $\dfrac{\frac{5}{32} \times 1000 \times 60}{2200 \times 15}$	$= 0{\cdot}29$,,
F.	Part off $\dfrac{\frac{5}{64} \times 600 \times 60}{2200}$	$= 0{\cdot}86$,,
G.	Index, etc. (4 faces)	$= 2{\cdot}00$,,
	Total	$= 11{\cdot}60$ sec.

A study of the machine might, of course, show this to require slightly modifying. In practice the calculation would have to be based on the cam cycle. It will be

noted that D is to take place during C. The times for A and C are assumptions which would not be very wide of the mark, probably, for most machines.

Cemented tungsten carbide tools are of little advantage on lathe work when all the power available can be used by high speed tool steel. One useful application has been noted on page 125. On some bronzes and cast iron work the carbide tools are undoubtedly excellent. There

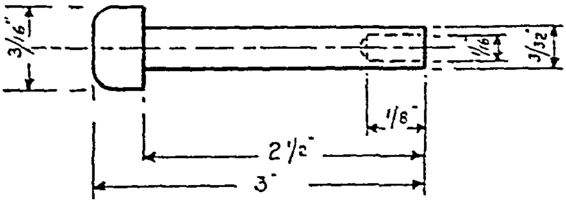


Fig. 26. Turning a Steel Component. Single-spindle Auto. Work

are many recent developments, and satisfactory tools for steel turning will probably soon be available. Something approaching the cost of high speed tool steel and as easily worked is desirable. Most of the new alloys or compositions are very expensive, difficult to work, and brittle. Yet it pays to use them in certain circumstances. In Chapter XI a hint is given on the method of ascertaining their economic worth. Tungsten carbide tools will cut cast iron well at from 150 to 250 feet per minute, the higher figure being for soft annealed castings with no hard edges. With a depth of $\frac{1}{20}$ inch and a feed of 0·025 inch per revolution, or a deeper cut and a finer feed, cutters will stand up a day or more without resharpening.

Using the same area of cut, the results are about the same with phosphor bronze at 600 feet and brass at 1000 feet per minute. When the cut is intermittent, a fine feed of about 0·006 or 0·008 inch should not be exceeded. Then the tips will have a long life if carefully used.

In spite of their less acute cutting angles they do not appear to absorb more power to remove a given quantity

of material. High speeds and very light cuts enable production to be rapid without straining the work and without heating it very much. There seems to be a possibility that if a cutting substance and machines could be provided for far higher speeds than are now dreamt of the power consumption might be actually decreased as compared with present experience.

Should such a substance be found, it is to be hoped that the resharpening of tools made of it will not be too difficult. One of the practical obstacles to the wider use of cemented carbide is that the ordinary operator or setter cannot grind it himself. It has to be specially done. This causes both delay and expensive duplication of tools.

CHAPTER VII

GRINDING

FOR the processes considered in previous chapters imaginary amounts were added to the real lengths (or breadths) of the components to make allowances for irregularities and trial cuts. In this chapter, devoted to grinding, imaginary alterations to sizes will also be made, but in a different way. This method of accounting for varying degrees of accuracy is, possibly, novel. It is certainly trustworthy; and it appears to be logical because the aiming at greater accuracy provokes effort which is closely akin to taking extra cuts in order to remove more metal.

For *external grinding* where D is the diameter of the work in inches, the

$$\text{R.p.m. of the work should be } \frac{160}{D}.$$

This corresponds to a surface speed of nearly 42 feet per minute. When the diameter is less than $\frac{3}{4}$ inch it is advisable to make sure that the machine will give approximately the ideal speed before basing calculations upon it. Of course work speeds other than those given by the formula may be successfully used, but they in conjunction with the following data are as efficient as any. Sound advice on the selection of wheels may readily be obtained from wheel makers. For machines engaged on miscellaneous work general purpose wheels have mainly to be used and this will often prevent the highest efficiency from being obtained. The wheel width (which varies roughly with the power of the machine) plays a great part in cutting times. Its inclusion in the formulæ which follow, and the adjustments which have to be made on account of the varying lengths of the stroke or pass to suit different components, make these formulæ appear to

be more complicated than those used in earlier chapters. The complications disappear when any particular case is considered, as will be seen from the examples.

By the *Stroke* or *Pass* is meant the longitudinal travel of the wheel in relation to the work between each reversal of motion. The pass in Fig. 27 measures P, as there indicated. The feed per pass depends largely on the stiffness of the work. Fig. 18 indicates weak and stiff shafts and Table XXXI gives the suitable feeds per pass. There is an important feature about these figures which must be emphasized: they are measured by the *reduction in the diameter*, not the radius.

TABLE XXXI

GRINDING FEED PER PASS (DIAMETRICAL REDUCTION)

Rough grinding—very stiff components .	. 0·003 in.
Ordinary grinding—stiff components . .	. 0·002 ,,
,, ,, —medium components .	. 0·0015 ,,
,, ,, —weak components. .	. 0·001 ,,
,, ,, —very weak components .	. 0·0005 ,,

(The basis in Fig. 18 is that a stiff shaft will stand a pass 3 inches long per revolution with 0·002 inch feed.)

When L = length to be ground and W = width of wheel, the length of one pass = L - W + 1 inch if there is a clear overrun at both ends. Many machines do not permit efficient short passes and when L is less than 2W but greater than W the grinding time will generally be the same as if L = 2W.

The traverse (or amount of pass) per revolution of the work equals (on the average and for time calculations)—

$\frac{1}{3}$W for work below $\frac{3}{4}$ inch diameter.
$\frac{1}{2}$W ,, between $1\frac{1}{2}$ inch and $\frac{3}{4}$ inch diameter.
$\frac{2}{3}$W ,, $1\frac{1}{2}$ inch diameter and over.

Number of passes per minute × length of one pass
= Total travel per minute.
= R.p.m. × W × $\frac{2}{3}$ (or $\frac{1}{2}$ or $\frac{1}{3}$ as explained above).

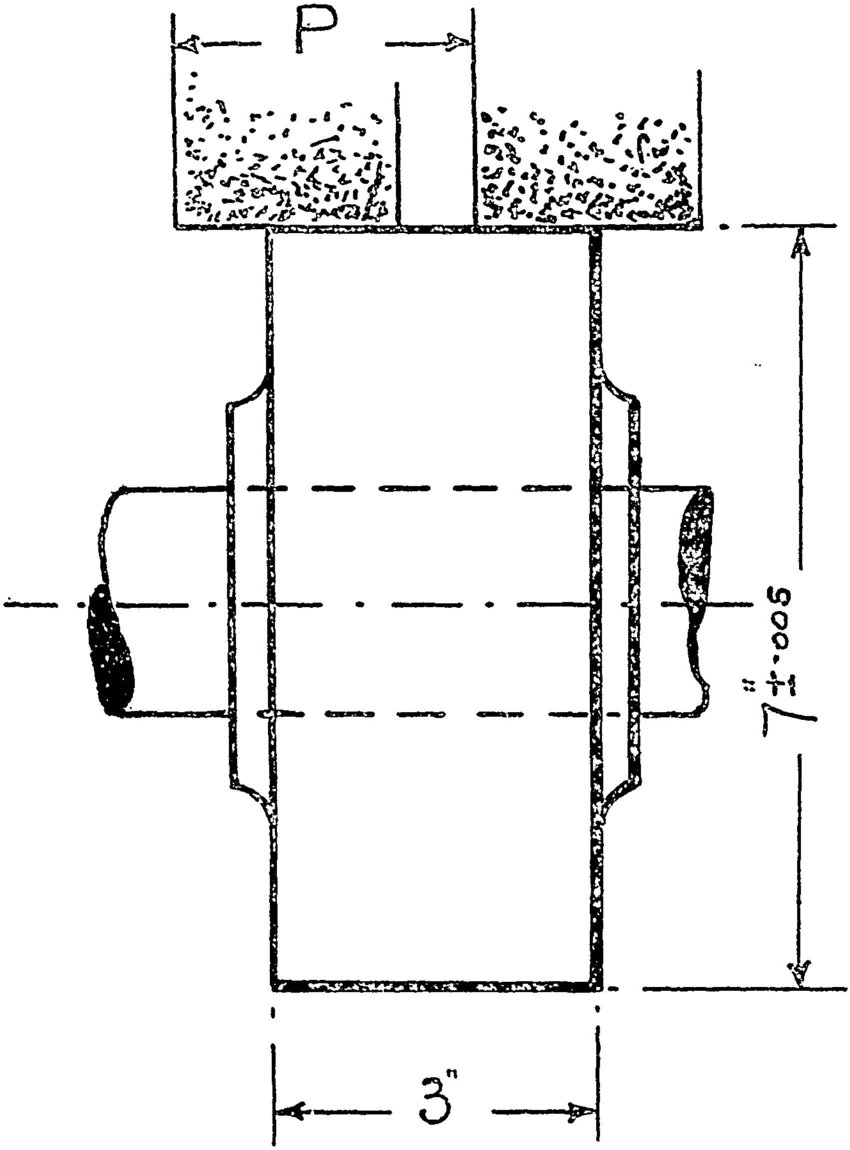


FIG. 27

Since the length of one pass $= L - W + 1$

$$\text{Number of passes per minute} = \frac{\text{R.p.m.} \times W \times \frac{2}{3} (\text{or } \frac{1}{2} \text{ or } \frac{1}{3})}{L - W + 1}.$$

(But not more than 60 unless the machine is known to be capable of more.)

The r.p.m. in the above formula refers to the work speed.

Actual cutting or grinding time

$$= \frac{\text{Grinding allowance} + C}{\text{No. of passes per min.} \times \text{feed per pass.}}$$

C = Compensation allowance. This is an imaginary addition to the grinding allowance to compensate for inequalities, for the extra passes necessary for grinding within fine limits, and any extra difficulty.

These additions may be as follows—

TABLE XXXII

COMPENSATION ALLOWANCES FOR SHAFT GRINDING

	Allowances
Tolerance exceeding Newall X . .	0·004 in.
,, equals Newall X or Y . .	0·007 ,,
,, ,, Z . . .	0·010 ,,
,, less than Newall Z . . .	0·015 ,,
Grinding taper to fine limits . . .	0·020 ,,
Grinding up to a shoulder, or shoulders .	0·006 ,,
Rough forged or black shafts . . .	0·030 ,, (or as judged).

The two last mentioned are extra to any other compensation. The last provides for the irregularities due to forgings being not quite straight or round. When grinding up to a shoulder extra passes are usually necessary to obtain parallelism. For grinding between two shoulders the length of pass is L – W. If there is only one shoulder allow L – W + ½ inch. When the length of the pass is less than 1 inch it is generally well to assume hand actuation at the rate of 60 passes per minute or the number of revolutions per minute, whichever is less.

The grinding allowance is the nominal amount to be removed from the diameter of the shaft to reduce it to the

desired size from that at which it was left by the preparatory operation. Suitable grinding allowances are given in Table XXXIII, but 0·010, 0·015 and 0·020 inch are often standardized.

TABLE XXXIII

GRINDING ALLOWANCES FOR SHAFTS

Dia.	*Length*					Limits for Turning ±
	0–6 in.	6¼–12 in.	12¼–24 in.	24¼–36 in.	36¼–48 in.	
½	·008	·010				·0015
1	·010	·012	·015			·002
1½	012	·012	·015	·020		·002
		0–12 in.				
2		·015	·020	·025		·0025
3		·017	·020	·025	·025	·003
4		·020	·025	·025	·025	·003
6		·022	·025	·025	·030	·004
8		·025	·030	·030	·030	·004
10		·030	·030	·030	·030	·005
12		·030	·030	·030	·030	·005

The rate of grinding is slowed down with short passes. At the end of each pass there is a slight dwell before the reversal takes place and the amount of feed is often restricted by the mechanism.

In the limiting case of *plunge grinding* L is nearly equal to W and the passes are small oscillations to prevent ridging the finished surface. On modern machines built for plunge grinding the rate of feed may be as in Table XXXIV.

Loading and unloading times may be as given for centre lathe work. A few seconds less may sometimes be given because the hold or grip for grinding does not require such heavy action.

Gauging also is slightly quicker, or requires less repetition, the grinding machine being better adapted for precision work than the lathe. When an automatic gauge

TABLE XXXIV

FEEDS FOR PLUNGE GRINDING

Diametrical Reduction per Revolution of Work

	$1\frac{1}{2}$ in. Wide	2 in. Wide	3 in. Wide
Very stiff components .	0·0025	0·0015	0·001
Stiff components . .	0·0015	0·001	0·0006
Medium components . .	0·001	0·0006	0·0004
Weak components . .	0·0005	0·0003	0·0002

is used 5 seconds will not be exceeded for fine limits and 2 seconds is plenty for ordinary work.

Wheel dressing time is generally covered by 10% of the cutting time. Winding the wheel across to make contact with the work and back again takes 5 seconds, on the average, for each shoulder. For simple work it may usually be reckoned that this manipulation is included in the compensation or other allowances. Special movements must be judged by their extent and complexity.

Preparation and setting times may be the same as for lathes, say 20 minutes for the two combined for small and medium size machines, with another 10 or 15 minutes if the wheel has to be changed. The reclamping of the tail-stock in a new position to suit a longer or shorter shaft generally makes machine adjustments necessary and trial cuts to get parallel grinding. Taper grinding is much worse: to set for tapers to fine limits allow at least another 10 minutes.

Five minutes is usually sufficient for fixing a steady unless it be of the three-jaw type as used on lathes. Adjustments are made as the grinding proceeds (except with the three-jaw type) without appreciable delay. For grinding a neck true to take a three-jaw steady rest in the centre of a shaft allow, on the average, $\frac{1}{2}$ minute.

Provided suitable wheels are used the data already given may be used for all kinds of materials. As in other machines, horse power determines to a large extent the

rate at which material can be removed. The power required to remove 1 cubic inch per minute is about the same as for milling. Fatigue allowance should include something for contingencies: fine limits are the rule, wheels do not always behave properly, and, on the whole, 15% is a fair average, although the work is not heavy. 20% is better if minor constituents are omitted.

The first example (Fig. 27) is a simple one with a clear overrun at both ends: a roller 7 inches diameter with a face 3 inches wide is to be ground within limits of $\pm$ 0·005 inch, the rough turned size being 7·010 inches. For grinding it is mounted on a stiff mandrel. The width of the wheel is 2 inches so plunge grinding, which would be slightly quicker, is impossible under the conditions.

$$\text{R.p.m.} = \frac{160}{7} = 23 \text{ (practically).}$$

L lies between W and 2W, so the time should be based on L being 2W or 4 inches. Hence

$$\text{Length of pass} = 4 - 2 + 1 = 3 \text{ inches.}$$

(If the length of pass used by the operator is shorter than this he may have to use a finer feed than will here be assumed.)

$$\text{Feed per pass} = 0{\cdot}002 \text{ inches.}$$

$$\text{No. of passes per minute} = \frac{23 \times 2 \times \frac{2}{3}}{3} = \frac{92}{9}$$

Grinding allowance	= 0·010 in.
Compensation allowance	= 0·004 „ (because of coarse limits)
Total	= 0·014 in.
Cutting time	$= \dfrac{0{\cdot}014 \times 9}{92 \times 0{\cdot}002}$
	= 0·7 min. (practically)
Wheel dressing	= 0·07 min.
Gauging	= 0·1 „
Load, etc.	= 0·5 „
FFT	= 1·37 min.

Possibly the cutting time would, in practice, differ a trifle from 0·7 minutes because the hypothetical r.p.m. and number of passes per minute could not be got exactly. But grinders engaged in miscellaneous production would be horrified at the idea of working at near this rate, and justly, for not without prolonged repetition could it be attained. For miscellaneous small lot production add 50% to the above FFT. The same will apply to the remaining grinding examples.

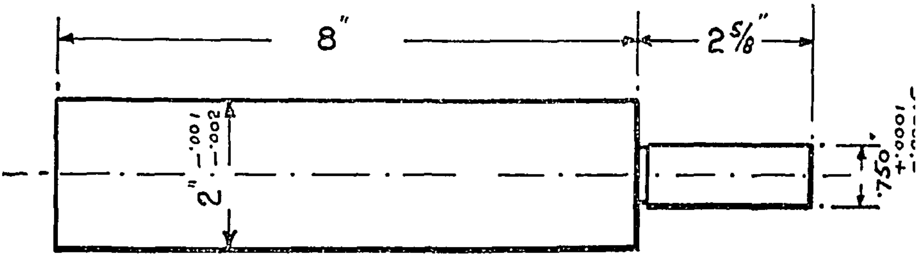


FIG. 28. GRINDING A SHOULDERED SHAFT

The shaft in Fig. 28 is to be ground, the amount left by turning being as shown in Table XXXIII.

Wheel width = 2 in. Consider the larger diameter first.

$$\text{R.p.m.} = \frac{160}{2} = 80.$$

Length of pass = 8 − 2 + 1 = 7 inches.
Feed per pass = 0·001 in. (because the shaft is weak).

$$\text{No. of pass per min.} = \frac{80 \times 2 \times \frac{2}{3}}{7} = \frac{320}{21}$$

Grinding allowance	= 0·015 in.
Compensation allowance	= 0·010 ,,
Total	= 0·025 ,,

$$\text{Cutting time} = \frac{0{\cdot}025 \times 21}{320 \times {\cdot}001} = 1{\cdot}64 \text{ min.}$$

Wheel dressing	= 0·16
Gauging	= 0·25 min. (less if a sizing appliance is used)
Load	= 0·5 ,,
FFT	= 2·55 min.

For the $\frac{3}{4}$ in. dia.,

$$\text{R.p.m.} = \frac{160}{\frac{3}{4}} = 214$$

Length of pass $= 2\frac{5}{8} - 2 + \frac{1}{2} = 1\frac{1}{8}$

Feed per pass $= 0{\cdot}001$ in.

$$\text{No. of passes per min.} = \frac{214 \times 2 \times \frac{1}{2}}{1\frac{1}{8}} = 190$$

190 is not practicable. Therefore assume 60 (page 153)

Grinding allowance $= 0{\cdot}012$ in.

Compensation $= 0{\cdot}021$ in. (Table XXXII)

Total $= 0{\cdot}033$ in.

$$\text{Cutting time} = \frac{0{\cdot}033}{60 \times 0{\cdot}001} = 0{\cdot}55 \text{ min.}$$

The next example (Fig. 29) is a slender forging to be ground on the $\frac{7}{8}$ inch diameter from the black with a wheel 4 inches wide. With a central steady the shaft will be of medium stiffness (Fig. 18).

$$\text{R.p.m.} = \frac{160}{\frac{7}{8}} = 180 \text{ (approx.)}$$

Feed per pass $= 0{\cdot}0015$ in. (Table XXXI)

Length of pass $= 18 - 4 = 14$ in. (no overrun)

$$\text{No. of passes per min.} = \frac{180 \times 4 \times \frac{1}{2}}{14} = \frac{180}{7}$$

Grinding allowance $= 0{\cdot}062$ in.

Compensation allowance $= 0{\cdot}034$ in. (Table XXXII)

Total $= 0{\cdot}96$ in.

$$\text{Cutting time} = \frac{0{\cdot}96 \times 7}{180 \times {\cdot}0015} = 2{\cdot}5 \text{ min.}$$

Wheel dressing	$= 0{\cdot}25$,,	
Gauging	$= 0$,,	(while grinding
Load	$= 0{\cdot}5$,,	
Grind for steady	$= 0{\cdot}5$,,	
FFT	$= 3{\cdot}75$ min.	

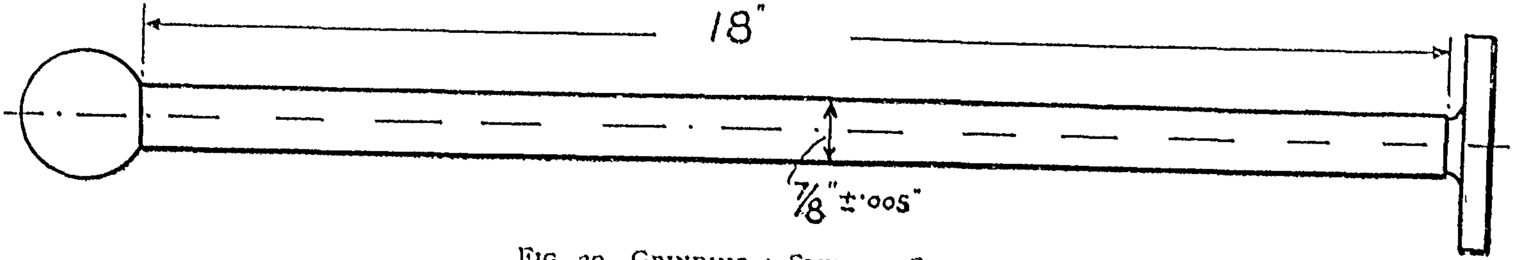


FIG. 29. GRINDING A SLENDER SHAFT

The calculations for plunge grinding are made like the preceding, the only difference being that the cutting time

$$= \frac{\text{Grinding allowance} + \text{compensation.}}{\text{R.p.m.} \times \text{feed per revolution.}}$$

Thus the cutting time for grinding a $1\frac{1}{4}$ inch (Newall) Z diameter 2 inches wide on a stiff shaft, would be

$$\frac{\cdot 012 + 0\cdot 010}{128 \times 0\cdot 001} = 0\cdot 18 \text{ minute.}$$

Internal Grinding.

Average feed (diametrical reduction)—

= 0·0001 inch for holes below $\frac{1}{2}$ inch diameter.

= 0·00015 inch ,, $\frac{1}{2}$ inch to $1\frac{1}{4}$ inch dia.

= 0·0002 inch ,, over $1\frac{1}{4}$ inch dia.

TABLE XXXV

GRINDING ALLOWANCE FOR HOLES

Dia.	Allowance	Boring or Drilling Limits ±
$\frac{3}{8}$	·005	·0015
$\frac{1}{2}$	·006	·0015
1	·008	·002
$1\frac{1}{2}$	·010	·002
$2\frac{1}{2}$	·012	·0025
3	·012	·0025
4	·015	·003

TABLE XXXVI

COMPENSATION ALLOWANCES FOR HOLES

	Allowances
When tolerance equals Newall B or over . . .	0·004 in.
When tolerance equals Newall A.	0·007 ,,
When tolerance is finer than A	0·010 ,,
Blind or shouldered holes	0·005 ,,
Taper holes	0·020 ,,

The loading constituent is about the same as for lathe work, or a trifle less as previously mentioned. Gauging is commonly as for lathes, too, but some regard must be paid to the amount of repetition. This applies to all gauging.

The work speed may be higher for internal than for external grinding. When D is the diameter of the hole

$$\text{R.p.m.} = \frac{240}{D}$$

If L is the length of the hole the length of one pass = L - W + ½ inch, but not less than 1 inch, except for hand traverse.

The traverse (or length of pass) per revolution of the work = ½ W on some and ¾ W on the best machines.

Small wheels are usually "square," i.e. W = D (approx.). This ratio holds roughly up to 1¼ inch diameter wheels. Above that the width must be ascertained in any particular case.

Number of passes per minute

$$= \frac{\text{R.p.m.} \times W \times \frac{3}{4} \text{ (or } \frac{1}{2} \text{ as the case may be)}}{L - W + \frac{1}{2}}$$

but not more than 60 on old-fashioned machines.

Modern machines are equal to anything likely to be desired.

For hand traverse of short passes 60 per minute is a safe allowance.

Wheel dressing absorbs about 10% of the cutting time for all except a few of the later machines on which wheel dressing is automatic. Small wheels have a short life and 5% of the cutting time must be allowed for wheel changing when grinding wheels of less than 1 inch diameter are used. This applies to all types of machines. It will be noted that modern machines are much more rapid than those of a few years ago; they travel faster and economize in wheel attention. Gauging and handling are

easier, too, but the gain in these is sufficiently covered by the reduced amount per component for the fatigue allowance.

The manner of calculating internal grinding time is the same as already explained for external work. If desired the various steps may be combined into one and the time obtained by substitution in one expression.

As before, the *Grinding Time*

$$= \frac{\text{Grinding allowance} + \text{compensation.}}{\text{Number of passes per min.} \times \text{feed per pass.}}$$

$$= \frac{(\text{Grinding allowance} + \text{compensation})\ (L - W + \tfrac{1}{2}).}{\text{R.p.m.} \times W \times \tfrac{3}{4} \times \text{feed per pass.}}$$

$$= \frac{(\text{Grinding allowance} + \text{compensation})\ (L - W + \tfrac{1}{2})\ D}{180\ W \times \text{feed per pass.}}$$

This is for modern machines. Old type machines are slower and 180 W should be replaced by 120 W. Variations in the speed and feed combinations should not affect the times very much. Unless they yield better than the formulæ indicate they should be adjusted, or better wheels obtained.

The time for grinding a hole $1\frac{1}{4} \pm \cdot 0005$ diameter, 2 inches long, with 0·010 inch to remove, will be

$$\frac{(\cdot 010 + \cdot 007)\ (2 - 1\tfrac{1}{4} + \tfrac{1}{2})\ 1\tfrac{1}{4}\ \text{minute.}}{180 \times 1\tfrac{1}{4} \times \cdot 00015}$$

$$= 47 \text{ seconds on a modern machine.}$$

It will be noted that the length W of the wheel is assumed to be $1\frac{1}{4}$ inches and the diameter also, although for a $1\frac{1}{4}$ inch diameter hole. For larger holes these relations do not hold, and must be judged.

Centreless grinding is rather special, but the following simple particulars may as well be given.

The two principal varieties are *Straight-through* and *Plunge.*

As a rule not more than 0·010 inch reduction in diameter should be made at each pass in *straight through* rough grinding; from 0·005 inch to 0·007 inch is more common and should not be exceeded if only two passes are to be made. For the semi-finishing pass 0·003 to 0·005 inch reduction is a fair amount. The finishing pass should be 0·002 inch or less for the best work. Long bars are often finished with 0·003 inch reduction.

When the amount to remove is 0·010 inch three passes. 0·005 inch, 0·003 inch, and 0·002 inch are usual and satisfactory. If the tolerance on the diameter is fine, say less than 0·00075 inch, one extra pass is usually necessary. By this is meant that by exercising great care, keeping machine and wheel in first rate order, it will sometimes be possible to avoid the extra pass. It will be unwise to reckon on that as a certainty. Similarly, if the tolerance is 0·0002 inch, or less, two extra passes will usually be necessary.

The rate at which the pass is made is affected by the class of finish desired. For work of the best quality the time in minutes for passing through 100 pieces of length L and diameter D $= L \times D \times 2$.

This is for grinding only and an addition must be made for wheel dressing, adjustments, fatigue, collecting the work, and placing it in readiness.

The basic time in minutes for 100 pieces may be taken as

$$(L \times D \times 2{\cdot}7) + \frac{L}{6} + 2 \text{ for each pass.}$$

For work of good commercial quality the basic time may similarly be reckoned as

$$(L \times D \times 1{\cdot}7) + \frac{L}{6} + 2 \text{ mins.}$$

Where quantities are small, the range in diameter considerable, and materials vary between soft and hard, a general purpose grinding wheel will be used (since

frequent wheel changing would be too expensive), and the basic time for 100 pieces should be close to

$$(L \times D \times 2{\cdot}5) + 2 \text{ minutes.}$$

In practice passes with the heavier cuts are about 15% slower than the mean figures given by the formulæ, and the finishing cuts are faster to balance.

The following examples will make clear the use of the formulæ—

Steel rods 10 feet long, $\frac{1}{2}$ inch diameter, are to be ground on a centreless grinder within limits $\dfrac{+\ {\cdot}000}{-\ {\cdot}002}$; 0·015 inch to remove.

Three passes of 0·008, 0·005 and 0·002 inch respectively will suffice. (It could be done in two passes, but in the long run there would be no time saved.)

The basic time per pass will average

$$(120 \times \tfrac{1}{2} \times 1{\cdot}7) + \frac{120}{6} + 2 = 124 \text{ minutes for } 100 \text{ rods}$$

and the 3 passes will take 372 minutes, including all allowances.

Steel tubes 2 inches diameter, tolerance 0·003 inch; 24 inches long; 0·015 inch to remove. General purpose machine.

Three passes will be required each averaging

$$(24 \times 2 \times 2{\cdot}5) + 2 = 122 \text{ minutes for } 100 \text{ components.}$$

But on a machine reserved for the job and well set up the time would be only

$$(24 \times 2 \times 1{\cdot}7) + \frac{24}{6} + 2$$

$$= 90 \text{ minutes for each pass for } 100 \text{ components.}$$

The formula for the basic time for *Centreless Plunge Grinding* is very easy to remember: the time in minutes for plunge grinding 100 components—

$$= 5 + (\text{grinding allowance} + \text{compensation}) \times 2000\,D.$$

Increase this time by 50% when the length ground is 6 inches and by 100% when 9 inches long for limits under

0·001 inch. This is on account of the difficulty in wheel dressing. Slides wear.

Compensation	= 0·010 if tolerance is		0·002 in. or over.
	= 0·015	,,	0·001 in. to 0·0019.
	= 0·025 ,,	,,	under 0·001 in.

For the best work two plunges will be necessary unless the grinding allowance does not exceed 0·006 inch. Each plunge will require the basic time given by the formula.

Observation will show that the actual grinding takes only about half the basic time.

Surface Grinding. The loading and unloading time amounts to about 4 seconds for each small article of a few square inches area, 6 seconds for pieces easy to handle and not over 20 square inches area, 10 seconds for larger pieces which yet are easily handled. By the area is meant the area of the largest face. The times are for steel or iron articles ground on a magnetic chuck. Heavy pieces will need loading times according to the shop facilities; when fixtures are used times depend on the holding devices. For cup wheel machines the depth of cut or feed per pass or revolution may be—

0·003 inch for roughing unless the surface is large and unbroken.
0·002 inch for general purposes.
0·001 inch for the last few passes for finishing.
0·0005 inch for finishing very fine work.

On circular table machines the mean peripheral speed may be 50 feet per minute if the surface to be ground is well broken up by intervening spaces. If it is nearly continuous 35 feet per minute will be high enough. Machines with reciprocating tables usually work more slowly, often at about half the above speeds. Moreover the wheel overruns the work at each end of the stroke as in face milling. For this overrun allow an amount D or the diameter of the cup wheel. D is somewhat excessive

in inches but not in time allowance, owing to the retard at reversals. Rotary machines avoid this overrun.

Surface grinding cutting time may be calculated by dividing the depth removed per minute into the total allowance. This equals the grinding allowance plus compensation suited to the condition.

The compensation allowance may be—

0·010 for 0·002 inch tolerance and over;
0·025 for 0·001 to 0·0019 inch tolerance;
0·040 for under 0·001 inch tolerance.

It is almost impossible to work within 0·001 inch on cupwheel machines and often difficult to get within 0·002 inch of flatness.

For each table load allow a 60 seconds constant for manipulation. Gauging time averages 30 seconds for each table load.

Thus the various constituents are, for one table load

Loading time = N × 4 or 6 etc. where N is the number of components in one load.

$$\text{Cutting time} = \frac{\textit{grinding allow.} + \textit{compensation allow.}}{\text{feed per minute}} \times 60 \text{ secs.}$$

Manipulation = 60 seconds.

Gauging = 30 seconds (average).

Wheel dressing = 10% of grinding time.

Fatigue, etc. = 15% of the sum of all the above constituents.

The number of components for a table load can best be determined by trial on the machine or on tracing paper. When that has been settled the time per table load and thence per component follows easily.

Example. Articles to be ground on a reciprocating machine which will hold 9 of them on its magnetic table require $\frac{1}{32}$ inch, removing from one side. Tolerance 0·003 inch. Diameter of wheel 14 inches. What would be a fair FFT if the length of chuck occupied by the

9 components equals 22 inches? Maximum traverse speed of machine is 15 feet per minute.

Loading time $= 9 \times 4$ seconds for the table load $= 36$ secs.

$$\text{Grinding time} = \frac{0.031 + 0.010}{\text{feed per minute}} \times 60 \text{ seconds.}$$

The feed per minute = feed per pass $\times$ number of passes per minute. Since the length of one pass is $(22 + 14)$ inches and the rate is 15 feet the number of passes per minute $= \dfrac{15 \times 12}{36} = 5.$

Hence feed per minute $= 5 \times 0{\cdot}002$ inch $= 0{\cdot}010$ inch and grinding time $= \dfrac{041 \times 60}{{\cdot}010} = 246$ seconds.

Manipulation	= 60 seconds.
Gauging	= 30 "
Wheel dressing	= 24 "
Total	= 396 seconds for 9 components.
	= 44 seconds each.

The amount to remove from a quantity of components is 0·010 inch. 30 will lie on the rotary table of a surface grinding machine. Tolerance 0·002 inch. What is a fair basic time?

Suppose it is found that when the 30 components are packed they lie between concentric circles of 40 and 24 inches diameter. The mean diameter on which to base the perpheral speed is then 32 inches. Some judgment must be used about this: if the greater part of the surface lies towards the outer circle a lower speed should be chosen. The nearest available speeds being 5 and 7 r.p.m. the lower would be taken for an estimate and an attempt should be made at the higher speed in the shops unless similar experiments had already proved that increased wheel wear or burning of the work would certainly be the result. A great deal depends on the position of the large

part of the surface in relation to the axis of rotation, as already stated, and selecting the right grade of grinding wheel.

The compensation plus grinding allowance = 0·020 inch. A feed of 0·002 inch per revolution will thus require 10 revolutions to be made and the remainder of the time calculation is as before.

Load 30 components at 6 secs. each	=	180 sec.
Grinding time $= \frac{10}{5} \times 60$	=	120 ,,
Manipulation	=	60 ,,
Gauging	=	30 ,,
Wheel dressing	=	12 ,,
		402 sec.
15% Fatigue, etc.		60 ,,
		462 sec.

Basic time = 15·4 seconds each.

It will be noted that the grinding time is so small compared with the FFT that it is not worth while forcing the cut if it is in the least detrimental to wheel or work.

CHAPTER VIII

SHEET METAL PRESS WORK

THERE are many changeable factors in press work: a superficial comparison of seemingly equivalent operations is often misleading. The primary constituent is handling, and the rate of the press is secondary except when the process is entirely automatic.

For small components the first operation is usually blanking from strip. Later operations and large blanks are commonly dealt with by separate hand feeding into the dies. Suitable lengths of strips range from 4 to 6 feet. Long rolls of strip are more adapted to automatic or roll feed. As a rule the longest dimension of the blank should lie across the strip since material is thereby economized. For example, a blank measuring 3 inches by 1 inch may require a strip $3\frac{1}{8}$ inches wide or $1\frac{1}{8}$ inches wide according to how it is placed in the strip. If there is also a space of $\frac{1}{16}$ inch between successive blanks the area of material used per blank by one method will be $3\frac{1}{8} \times 1\frac{1}{16}$ square inches, and by the other $1\frac{1}{8} \times 3\frac{1}{16}$ square inches, a difference of nearly 4%. But this is not all: the shorter the blank lengthways in the strip the less the waste at the ends (as a rule); with the narrow strips more strips have to be handled for a given quantity of blanks and time is thereby lost. Sometimes the way of the grain or fibre in the blank must be taken into account (the material may stand a sharp bend in one direction and not in another) and then it may be preferable to use the narrow width. Alternatively the strips may be cut across the grain.

The principal factors which determine the rates of blanking from strip are—

1. Number of blanks cut per working stroke.
2. Thickness of strip.

3. Width of strip.
4. Length of feed between working strokes.
5. Number of working strokes per minute which the press will make.
6. Kind of stop used to determine feed between strokes.
7. General convenience and accessibility.
8. Means for dealing with swarf.
9. Means for collecting blanks.

With the best feed stops a good percentage of the possible strokes can be made during the feeding of the strip. Except with operators of unusual skill poor stops lead to missing a large proportion of the strokes; and no stops at all lead to a gross waste of material through irregular spacing. Strokes have to be missed in any case while the hold on the strip is changed during feeding. To minimize handling it pays to make provision for the operator to lay 3 or 4 strips on a board conveniently placed so that the stoppage through bending to pick up fresh strips occurs less frequently.

For small strips about 15 seconds for picking up, entering in the dies and starting is sufficient. This includes a small amount of transport which is sure to occur; unfortunately the transport, that is moving the bulk supply into a convenient place, is often neglected, and a good deal of production is thereby lost. This 15 seconds is shared equally among the blanks produced per strip; obviously the more blanks per strip the better.

The blanks have to be collected and swarf disposed of: 10 seconds for each small strip is reasonable as an average figure to include both constituents. For missed strokes 40% of the maximum possible is a reasonable amount to allow for simple light work.

On these assumptions blanking 50 components (singly) from a strip 6 feet long on a press making 80 strokes per minute will take—

Inserting and starting strip . . .	15 sec.
50 working strokes $\frac{50 \times 60 \times 100}{80 \times 60}$ . .	63 ,,
Swarf, etc.	10 ,,
Total for 50 blanks . . .	88 sec.
25% fatigue and contingencies . .	22 ,,
	110 sec.

This gives a rate of 3·6 minutes per 100 blanks. Any press operation can be estimated as above, though it is an unusual method. More commonly the rate is guessed, from experience, at so many hundreds per hour, according to the press to be used and the kind of work to be done on the component. In many works the real speed possibilities of press production are unknown because production is mixed up with tool setting, breakdowns, and transport of material. It is difficult to make a clear separation when small quantities are the rule.

For the present purpose, and for studying actual working in a press shop with a view to improving efficiency, the method of constituents is the best. It is not practicable to produce every job with the ideal machine and tools. Therefore the method of estimating production rates must, to be satisfactory, take into consideration the probable conditions. Analysis into constituents as set out below provides a reliable way of ensuring due attention to every circumstance. Of course a jump of 4 seconds such as is indicated in the following data for the difference in time for loading a medium size and a large blank does not mean that there is really a sharp dividing line: intermediate times may be chosen if desired. Nevertheless the stated times will be found safe to estimate upon and for a measure of efficiency.

DATA FOR PRESS WORK

Strip Insertion. 15 seconds generally, but up to 30 seconds for exceptionally heavy or wide strip. This

covers picking up and inserting the strip and a small amount of transport with a single operator.

When strips are fed from front to back a common practice is for the operator to feed and blank a short length, next to withdraw the strip, reverse it, push it right through, then to blank, pulling it towards him between strokes. This method is not economical as regards either material or press time. It is better to use stops and employ a youth at the back for pulling through. Safety guards must be fixed at the back and front in that case, but the back guard can be a simple affair. Much is made of saving a "ha'porth of labour," but eyes are shut to the ensuing waste of machine time.

Effective Strokes per minute while Feeding Strip.

Roll feed. Maximum which the press will make.

Hand feed. The proportion of effective to maximum possible number of strokes averages as follows—

With first-class stops—

60%	plain blanking	—short steps
40%	,,	—long steps

With inferior stops—

40%	,,	—short steps
25%	,,	—long steps

The same rates apply for combination tools when arrangements are satisfactory for preventing swarf trouble or other interference. Follow-on tools require double stops: with good stops 5 seconds extra per strip suffice, but poor stops result in the effective percentage of strokes being reduced to 30% for short and 20% for long steps. The 5 seconds for double stopping are still to be added.

Number of Strokes per Strip

$$= \frac{\text{length of strip} - \text{waste at ends.}}{\text{length fed between strokes}}$$

Number of Blanks per Strip:

Number of blanks per stroke multiplied by number of strokes per strip. In the case of follow-on tools there is one extra stroke and when there are multiple punches there are sometimes end strokes which do not produce a full number of blanks.

Inserting Blank or Pressing into Die—

Very small components—about	4 in. × 4 in.	.	2 sec.
Small components — ,,	10 in. × 10 in.	.	4 ,,
Medium components — ,,	18 in. × 18 in.	.	8 ,,
Large components — ,,	48 in. × 18 in.	.	12 ,,
Very large components — ,,	72 in. × 48 in.	.	20 ,,
	(two operators feeding)		

Add 2 to 15 seconds if location is not perfectly simple, according to the circumstances.

No transport is included in the above times, which are for thin gauge materials. When increased thickness makes handling more difficult more time must be allowed as judged desirable. Location is supposed to be straightforward—against pegs or in a simple register. More difficult locations must be allowed extra.

Ejection or Removal of Pressing from Dies—

0 if work is pushed through the die.

2 seconds for small components if they can be easily withdrawn and pushed aside.

Frequently a flick suffices, especially on fly press work and then 1 second is ample. Allow 5 seconds for medium size work and 8 seconds to extract and set down large components. Very large components need 15 seconds.

Swarf disposal. 0 for raising or bending. 10 seconds per strip after blanking is an average figure. From 2 to 5 seconds per pressing when they are separately fed. This figure seldom need be increased, for in the case of large work part of the work can be done by the helper while the opposite side is being fed and operated.

Planishing. Small burrs are often removed (or made harmless) by passing such items as small transformer laminæ through a pair of rolls. One operator can feed from 2,000 to 4,000 an hour according to size. A fly press is as good as anything for medium quantities of small pressings. 1,000 an hour is an average rate for the lightest work. This comes down to 600 an hour for a piece measuring about 3 inches × 2 inches × $\frac{1}{8}$ inch. 20% is enough for fatigue and contingencies and is included in these times. When a power press is used more than one piece at a time may be laid on the lower plate, perhaps. This has to be considered in conjunction with the rate of the press.

Dial Feed. As for roll-feed, but the handling time must be considered if it affect the rate.

The nominal pressure which a press will exert is not a reliable guide to its rate of working. A geared press suitable for thick material will work at, perhaps, half the speed of an ungeared press which will deliver the same pressure. Consequently the rate of the press which will be used must be ascertained for accurate estimating. As a rough guide the following table may be used—

TABLE XXXVII

POWER PRESSES—STROKES PER MINUTE

Nominal Size	*Ungeared Presses*	*Geared Presses*	*Drawing Presses*
Maximum Pressure in Tons	Thin Material	Thick Material and Drawing	Long Stroke
Up to 10 .	120	—	—
„ 20 .	100	50	30
„ 40 .	80	40	25
„ 60 .	60	30	20
„ 100 .	30	15	10
„ 150 .	20	10	7
„ 200 .	15	8	5

On fly press work the preceding data for loading, etc., apply. The time per swing may be taken as—

Very light small swing	1 sec.
Light swing	2 ,,
Medium swing	4 ,,
Heavy or long swing.	8 ,,
Very heavy or long swing	10 ,,

Examples where these would apply are given later. For second operation work or blanking from sheets already cut to size to make one component the constituents are—

Clean and grease (if required)
Insert in die
Actuate press
Eject or remove
Dispose of swarf (if any)

These apply to all types of machines.

Greasing is only required for drawing. Swarf occurs when there is blanking, trimming, or piercing. On small presses the stroke is so rapid that handling practically entirely governs the rate of production. With large presses the picking up of a new piece ready for insertion can often be nearly completed while the ram is moving.

As a guide to the rates usual for second operation work, including 25% fatigue and contingency allowance, about 600 per hour can be expected from small presses if there is no swarf to get rid of. This sometimes is a trouble; when trimming, for instance, it may hang around the punch and cause considerable delay until means of stripping it are provided. An air blast is useful for small piercings of thin material. No rule can be given—each case must be judged on its merits, or rather, defects, for with good tools the trouble is small.

For medium size presses, where two hands are required to handle the components, the rate per hour is about 400.

Thin sheets (say less than $\frac{1}{8}$ inch thick) measuring about 24 inches $\times$ 12 inches can be got off at nearly the

same rate for short periods, but over a day it is not wise to reckon on more than 200 an hour. Larger sheets, measuring about 36 inches $\times$ 18 inches, take the same time, but require two operators, one on each side of the press. Still larger sheets require one operator to feed and work the press, one to pick up the sheets and assist to feed and one man at the back to remove the work. Two men at the back are necessary if there is swarf to remove or the sheets are very large. 120 an hour is an average rate. If the sheets require cleaning and oiling one or two men (according to the size of the sheet) are required in addition to the press attendants.

Frequently in second operation work two components are loaded together and dealt with in one working stroke. In that case the time for each will be about $\frac{2}{3}$ of the time for doing them singly.

It should be noted that the rates per hour given above do not apply to slow-moving drawing presses.

Combination tools which pierce and blank simultaneously cost considerably less than separate tools for blanking and piercing. Unless the holes lie close together in a small part of the blank the separate piercing tools would be nearly as large as the blanking tools. The combination therefore saves a great deal of material and machining, besides yielding more accurate work with half the setting time and less than half the operation time. The common rule for the smallest diameter which can be pierced in a sheet or plate is that it should not exceed the thickness pierced. It is safe to follow.

As an aid to setting, *pillar type tools* are easily worth the extra first cost unless but few components are required. They save in setting time and greatly prolong the life of the dies by avoiding the misalignment which frequently occurs without them.

On the whole it pays to avoid "cleverness" in designing press tools. Simple tools in the long run usually give the best economy. Exceptions to this rule should be permitted

only when very large quantities of components have to be produced from the tools, and designs are stable. In ordinary engineering work these conditions exist only occasionally. Even then simple tools are usually made at the onset because production is quickly desired and the more complex tools may take months to get working properly.

The fatigue allowance in press work should be generous. It must include something for contingencies: although setting may be regarded as an extra and be separately allowed for, press tools are liable to sudden trouble besides failure through wear. On the whole the fatigue plus contingency allowance should seldom be less than 25% of the floor to floor time, the latter, of course, taking into account strip or blank feeding in addition to the period elapsing between successive working strokes, and setting being extra. For long runs, when tools will need to be replaced at intervals by a resharpened set, 15% fatigue plus 15% for tools (including setting) is none too much. Average setting time for pairs of tools are given in Table XXXVIII. They are for pillar type tools on power presses. Stripping down, as well as setting, is included, and so are preparation and recording.

TABLE XXXVIII

PRESS TOOL SETTING TIMES

Approximate Weight of Tools	No. of Men	Time in Minutes
Under 56 lb.	1	30
,, 1 cwt.	2	30
,, 2 cwt.	2	45
,, 5 cwt.	3	60
,, 10 cwt.	3	90
,, 1 ton	4	120
,, 2 tons	5 (including crane driver)	120
,, 5 tons	6 ,, ,,	180
,, 10 tons	6 ,, ,,	240

Of course much depends on the facilities provided and whether there are many or few making up blocks for closed height adjustment. On small work it is desirable to have fewer operators than presses when short runs are common.

The storage of large press tools is a great nuisance. If they are not accessible to a crane much time is wasted. If they are accessible valuable floor space is occupied by them lying idle. Perhaps the best solution in many circumstances is to provide a strong high platform for the press tool stores, using it for the heavy tools and the floor underneath for the smaller tools or as a sheet metal stores.

Foot or kick presses are a trifle quicker for production than fly presses because they leave both hands free. But so many accidents are caused by kicking at wrong times that it is better to avoid them. An exception may be made when the lift of the ram is too little for fingers to be inserted. This restricts the kick press to such work as piercing and cutting off from strips of thin material such as are used for electrical insulation. For such work the speed is quite good, being about 1500 per hour for pieces 2 or 3 inches long, and 1200 for pieces 1 foot long, fed to stop from the roll. These rates include fatigue. But the great advantage is that the material can be kept free from oil or dirt more easily than in the ordinary press shop, the pieces being cut off near where they are to be used.

The capacity in tons of power presses is given roughly (for workshop calculations) by

$$\text{Maximum pressure in tons} = 3\,D^2$$

when D is the diameter of the crankpin. This is for presses driven from one end of the shaft. For presses driven from both ends the capacity is about 50% greater. This rule is useful as a guide and is well on the safe side for ordinary conditions.

The maximum pressure required to shear an area of

1 square inch varies somewhat with the state of the material but the figures below will be found sufficiently near for most purposes.

TABLE XXXIX

SHEARING RESISTANCE OF SHEET MATERIALS

Material	Tons per Sq. In.
Aluminium	5
Brass (soft)	12
„ (hard)	18
Bronze	19
Copper	12
Fibre	11
Iron (wrought)	18
Steel (mild)	22
„ (alloy, heat-treated)	40
Tin	2
Zinc	7

The formula for the maximum pressure P for shearing through a thickness T and periphery L when the material has a shearing strength f in tons per square inch is

$$P = L \times T \times f$$

By putting angular shear into the die or the punch the load is distributed over a longer time and the maximum pressure is reduced by about 25% when the total amount of shear $= \frac{1}{2}T$, 50% when it $= T$ and 70% when it $= 2T$.

The pressure required to blank a hole 3 inches diameter through mild steel $\frac{1}{8}$ inch thick will be

$$\pi \times 3 \times \tfrac{1}{8} \times 22 = 26 \text{ tons.}$$

This is for tools without shear. A 30-ton press would be chosen. But a little shear, say $\frac{1}{16}$ inch, would reduce the maximum pressure to below 20 tons.

The crankpins of a press are 6 inches diameter. The shaft is driven by gearing at both ends. Will it be powerful

enough to cut a blank from $\frac{1}{8}$ inch thick aluminium sheet if the periphery of the blank is 240 inches?

The area to shear is $240 \times \frac{1}{8} = 30$ sq. inches.
Pressure required $= 30 \times 5 = 150$ tons.
By the rule just given the capacity of the press is

$$6 \times 6 \times 3 \times \frac{150}{100} = 162 \text{ tons.}$$

It will do the work without shear on the tools. Yet shear will be desirable since it will relieve the shock.

The peripheral length of a circular or rectangular blank is easily calculated. For irregular shapes the readiest method is to try the length with a piece of raffia or other stretchless string laid on the accurately drawn shape. Some despise this method. But why be meticulous? When it happens that the load seems rather too heavy for the press which otherwise would be preferred, the measurement can be made more carefully than usual. It is ridiculous to find out, laboriously, that the blanking pressure required is, say, 49·41 tons when the choice lies between a 30-ton and a 60-ton press.

The problem of finding the developed shape of a raised or drawn component is not difficult to solve approximately. The final result is always got by trial except for the simple folding of thin material. When metal is bent, or raised, or folded (all three words are used for the process) it stretches more than one without experience would expect. If the inside radius of the bend is R and the thickness of the metal is T the effective radius may safely be taken as

$$R + \frac{T}{3}.$$

That is, the length of the metal in the curved part from A to B in Fig. 30 is $\frac{\pi}{2}\left(R + \frac{T}{3}\right)$.

For finding approximately the shape and size of blanks which are to be raised and folded in various directions the shape of the blank may be set out by projection.

Sometimes this is rather a complex business, and it is easier and quicker to build up a paper model, Kindergarten fashion, by gumming sections together.

When material is drawn into a bowl or cup the weight of the finished component plus what is trimmed off or pierced out will equal the weight of the original blank. It follows that the size of the blank can be calculated. But materials are not uniform and the calculations involved are frequently intricate and not quite reliable.

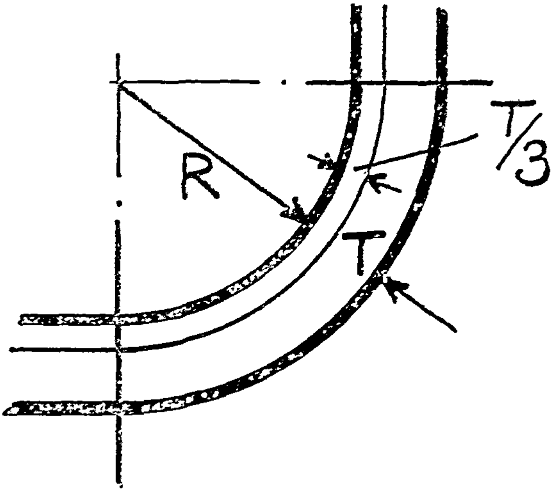


FIG. 30. RADIUS OF BENDING

Often the thickness of the walls of the cup are supposed to be the same as that of the original blank. Although that may be intended, flanges under the pressure plate tend to thicken and other walls are stretched. For this reason many engineers base the size of the blank on the *inside* dimensions of the finished shell and invariably find plenty of metal in it. Trimming is always necessary after deep drawing and must be allowed for in the operations and in the size of the blank.

There is a simple, practical way of finding the diameter of round cups of any shape. It is more suitable for shallow cups than deep ones but is well adapted for workshop use or estimating. An example will illustrate the

method, which is based on the well-known principle of Guldinus, though it appears to be unknown to press tool engineers. The size of the blank for the pressing shown in Fig. 31 is required. Lay on the inside profile a copper (or other soft metal) wire as shown at A-B. Cut it to terminate exactly at A and B. Then balance the wire on the blade of a knife at C so that the imaginary axis DE is vertical; that is, if the wire were swept around this

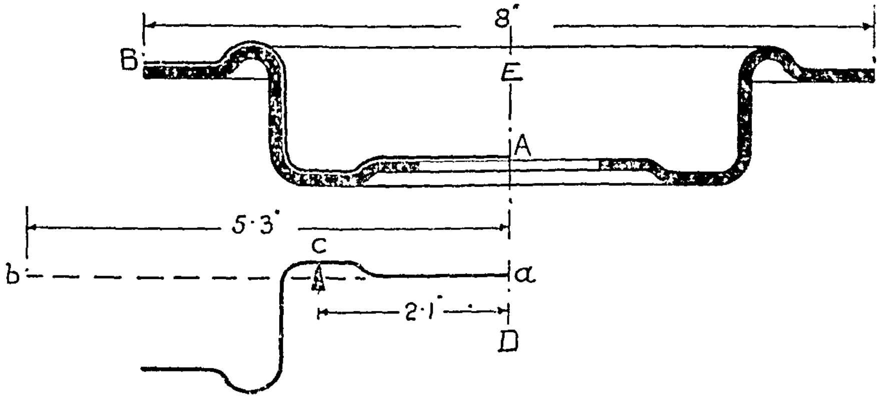


Fig. 31. Finding Blank Diameter for Cup-shaped Pressings

axis it would generate a true copy of the desired inside formation of the shell. Measure the length AC. Straighten the wire and ascertain its length l = ab. Then the area of the blank will be

$$2\pi \times \text{length CD} \times l = 2\pi \times 2{\cdot}1 \times 5{\cdot}3 = 70 \text{ sq. inches}$$
and the blank diameter $= 9\frac{1}{2}$ inches nearly.

This supposes that it is intended that the wall thickness of the shell shall be approximately $\frac{3}{16}$ inch throughout. If there is much slope at the point C the knife blade should be replaced by a cotton thread hitched around the wire. Small cups should be drawn out to a large scale to reduce errors in measurement.

When the size of the blank is known a suitable press can be selected, the maximum blanking pressure being found by the formula on page 179. If holes are pierced

at the same time the extra load must be added in proportion to their united periphery.

The rule for the amount of material surrounding a pierced hole in a blank or a strip is that it should not be less wide than thick. Thus a blank 6 inches wide across a strip $\frac{1}{8}$ inch thick necessitates the strip being $6\frac{1}{4}$ inches wide. The rule is safe; it can often be relaxed a little in practice as regards contiguous piercings near the centre of a strip, but not when they are near the edges if it is desired to keep the frame of the strip intact. For thin materials it is often better to allow a trifle extra margin at the edges—not less, say, than about $\frac{3}{64}$ inch on each side but so as to keep the strip to a "round figure" width. It must be remembered that strips are not cut quite accurately parallel, and widths appreciably vary from strip to strip.

Bending consumes about half the power needed for drawing, and the pressure on a drawing punch is about the same as would be required for blanking out the bottom of the formed cup; at any rate it is near enough to guide in the selection of a press unless there is a very severe extending or ironing action. Drawing presses in common use vary in their speeds from 3 to 30 strokes per minute according to power and length of stroke. Before the time can be accurately estimated the speed of the press must be known.

Loading may include unloading or not, according to whether the cup is ejected and has to be removed or is pushed through. Small ejected cups will usually take about 5 seconds for loading and unloading. The time for larger ones must be judged by the trouble in handling them. Loading alone will take 3 seconds for small cups and upwards as judged for large ones. Short runs can be done at an average of 2 seconds, but it is unwise to take that as a basis. Sometimes the operator has to do a little stoning to the drawing tools, sometimes the roughness which develops is attended to by the setter or by a

tool maker. Delay through this must be allowed for in the time allowance. The constituents entering into the basic time are—

Loading time (this will include time for oiling or greasing)
Time for one stroke of press
(Possibly) Unloading time
Tool attention
Fatigue

The last two may be put together and reckoned at 40% of the sum of the others. More is necessary if many shells burst. There is usually an allowance also to be made for trucking the pressings from machine to machine; it may easily amount to 10% of the floor to floor time. Evidently a good tool service and plenty of labourers are essential to an efficient press shop. The tendency is to starve labouring help because for an operator to move a truck consumes only a few minutes. But the repetition of that movement several times a day eats away a serious proportion of the effective working period.

The deep drawing of cylindrical shells is governed by the following approximate rules—

For *double action drawing* allow reductions in diameter of 33⅓% for the first, 25% for the second, then 20, 15 and 10% for successive later draws. Under favourable conditions with thick materials—say over ⅛ inch thick—the first reduction may be 40%, the second 33⅓%, and then 25% for the next and later draws.

For *single action drawing* allow sometimes 30% but more usually 25% for the first and second, and 20% for the third and later draws with thick material. Allow 25%, 20%, 15% and 10% for thin materials. When estimating allow for annealing before the second and later draws although it may be found, by trial, that an annealing can sometimes be omitted when the reductions are small.

When the shape drawn is not round the matter is more difficult. For the present purpose, which is concerned with the approximate size of the blank (as it affects the quantity of material used) and the number of draws (as that affects time), the following notes may be useful.

Simple bending does not cause any great flow of metal along the surface of the dies; there is a slight movement

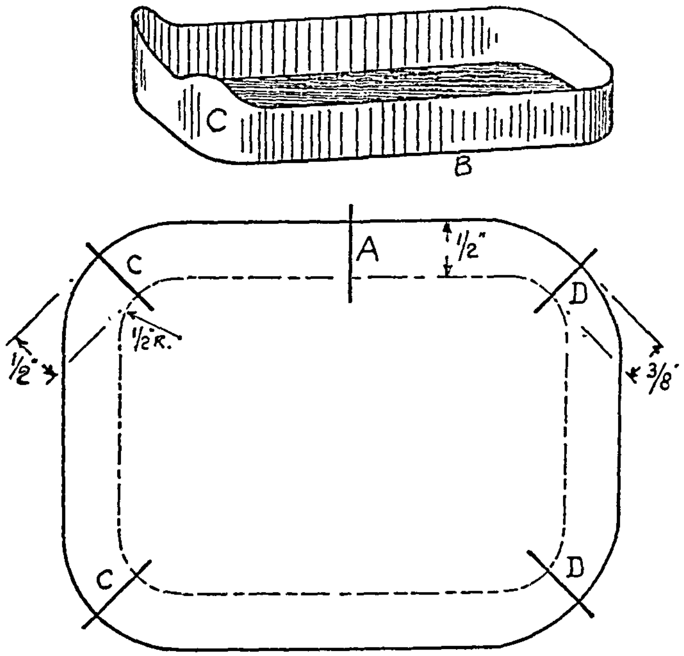


FIG. 32. RAISING A SHALLOW PAN

where the bend is concentrated but nothing which tends to alter much the thickness of the metal there.

When metal is *drawn* in press tools it is bent, compressed and extended at the same time; the metal is forced to flow along the surface of the dies and, more often than not, in such a way that the original blank thickness is maintained, approximately, in the completed shell.

In the case of round shells the action is symmetrical and can be calculated fairly nearly. Where other shapes are made, the forces are unequally disposed; calculations

give, perhaps, a close idea of what may happen but only trial is depended on for finding exactly the shape and size of blank. A simple example will show the idea. Fig. 32 represents a shallow pan of thin material to be formed from a flat blank. Although the bottom corners B are to be assumed square they could not, of course, in practice be drawn so in dies. A radius there would complicate the arithmetic and serve no useful part in the study. It may be allowed for as shown in Fig. 30.

Consider a line A near the centre of one side of the pan. In that region there will be practically simple bending, no drawing of the metal. Hence, if the blank measures $3\frac{3}{4}$ inches across and the inside of the pan is to be $2\frac{3}{4}$ inches, the height of the flange will be close to $\frac{1}{2}$ inch. But near the line C there will be quite a different action. If the blank were made at 1 inch radius at the corners the effect at C would closely resemble that of drawing a cylinder 1 inch diameter from a blank 2 inches diameter. The height of such a cylinder is obtainable from the formula

$$h = \frac{D^2 - d^2}{4d}$$

where D = diameter of blank, h = height, and d = diameter of cylinder. In this case

$$h = \frac{4 - 1}{4} = \tfrac{3}{4} \text{ inch.}$$

That is, the flange would be $\frac{1}{4}$ inch higher at C than at A as shown at the left hand of the figure. The profile shown by the chain dotted line represents the plan of the raised pan. The corners D are corrected as regards the blank to give a level raised flange as shown in the view above them. As an application of the formula will show, the blank should extend at D for a distance of only $\frac{3}{8}$ inch beyond the dotted outline instead of $\frac{1}{2}$ inch as along the flat sides.

It is generally possible to estimate fairly closely the shape and size of the blank required for any purpose by judging at what places there will be simple raising, where real drawing, and applying the common rules of mensuration. The amount of flange for drawing between the die and the pressure plate varies from about ½ inch for small components up to 3 inches (i.e. 6 inches total width) for large ones in its least width after drawing.

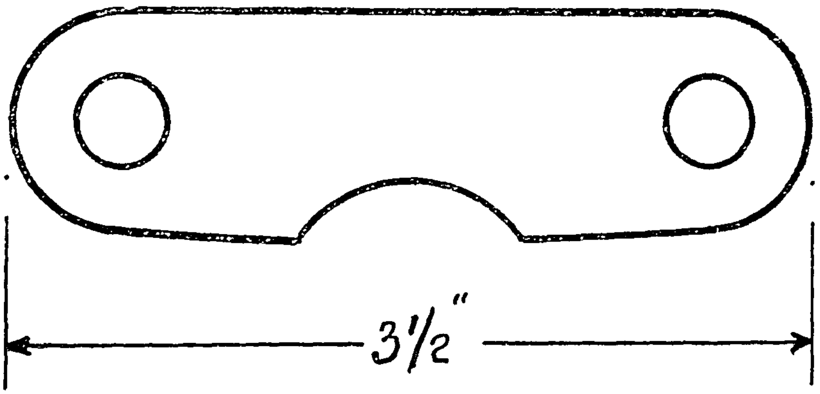


FIG. 33. STAMPING WITH FOLLOW-ON TOOLS

The following examples indicate briefly the application of the rules and data which have been given—

FIG. 33. 16 S.W.G. M.S. 20-ton press. 100 S.P.M.

Follow-on tools. Poor stops. 67 blanks per strip.

67 + 1 strokes take $\frac{68 \times 60}{30}$	= 136 sec.
Stops	= 5 ,,
Strip and swarf	= 25 ,,
	166 sec.
25% fatigue	= 41 ,,
Time for 65 blanks	= 207 sec.

Time % = 309 sec.

Planish on fly press—1,000 per hour

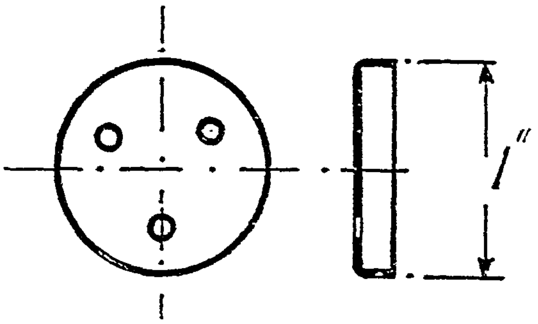


FIG. 34. STAMPING WITH COMBINATION TOOLS

FIG. 34. 20 S.W.G. M.S. 10-ton press. 120 S.P.M.

Combination blanking and raising tools. Inclined press. Treat as for long steps, to give time for pressings to clear. Good stops. 46 blanks per strip.

46 strokes take $\frac{46 \times 60 \times 100}{120 \times 40}$	= 58 sec.
Strip and swarf	= 25 ,,
	83
25% fatigue	= 21 ,,
Time for 46 pressings	= 104 sec.
Time %	= 226 sec.
Pierce holes on fly press.	
Load	= 2 sec.
Swing	= 2 ,,
Eject	= 2 ,,
	6
25% fatigue	= $1\frac{1}{2}$,,
	$7\frac{1}{2}$,,
Time %	= 750 sec.

If the loading had required an angular setting it would have needed another 2 seconds.

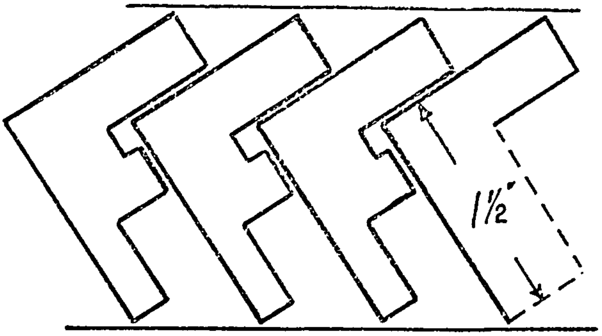


FIG. 35. STAMPING LAMINAE—A WASTEFUL METHOD

FIG. 35. 22 S.W.G. M.S. 10-ton press. 120 S.P.M.
Good stops—87 blanks per strip.

87 blanks take $\frac{87 \times 60 \times 100}{120 \times 60}$	=	73 sec.
Strip and swarf	=	25 "
		98
Fatigue 25%	=	24 "
Time for 87 blanks	=	122 sec.
Time %	=	140 sec.
Area per blank	=	1·7 sq. in.

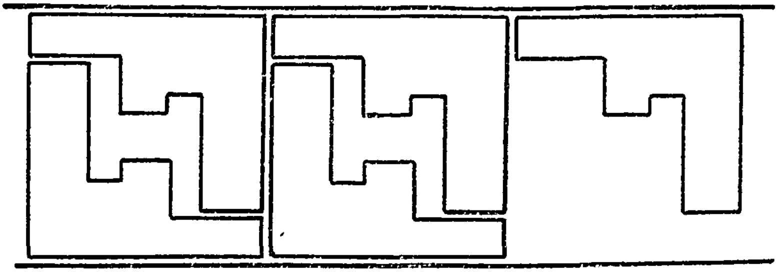


FIG. 36. STAMPING LAMINAE—AN IMPROVEMENT ON FIG. 35

FIG. 36. Same blank as in Fig. 35. 20-ton press 100 S.P.M.
Good stops, 2 blanks per blow. Treat as follow on tools—

45 + 1 strokes take $\frac{46 \times 60}{40}$	=	69 sec.
Starting stop	=	5 "
Strip and swarf	=	25 "
		99 sec.
Fatigue 25%	=	25 "
Time for 90 blanks	=	124 sec.
Time %	=	138 sec.
Area per blank	=	1·3 sq. in.

This shows the economy of the second method.

FIG. 37. The formation of the curl is the only operation of particular interest. It is to be done on a fly press, about a mandrel, having been previously raised as shown by the dotted profile A.

Load	2 sec.
Insert mandrel	4 ,,
Swing	10 ,,
Remove mandrel	5 ,,
Unload	3 ,,
	24 sec.
Fatigue	6 ,,
Time each	30 sec.

This is not a quick method compared with some but it suffices for many components made in small quantities.

FIG. 38. $\frac{1}{8}$ in. M.S. 70-ton press. 30 S.P.M.

Made from rectangular blanks. Combination blanking and piercing tools.

Blank and pierce—

Insert blank (rough location)	4 sec.
One stroke	2 ,,
Remove blank	2 ,,
Remove swarf	3 ,,
	11 sec.
Fatigue 25%	3 ,,
Time each	14 sec.

Raise two small flanges. Power press—

Load (precise location)	6 sec.
One stroke	2 ,,
Remove blank	2 ,,
	10 sec.
Fatigue 25%	$2\frac{1}{2}$,,
	$12\frac{1}{2}$ sec. each

Raise channel. As for raising flanges.

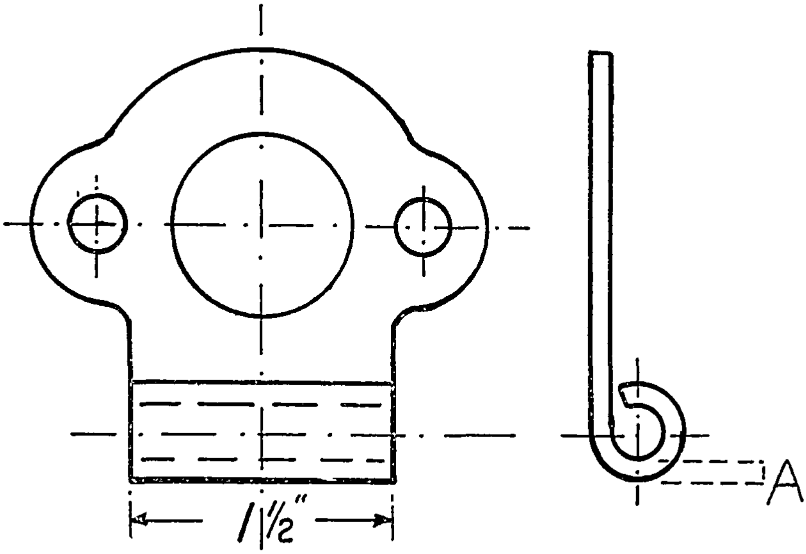


FIG. 37. CURLING ON A FLY PRESS

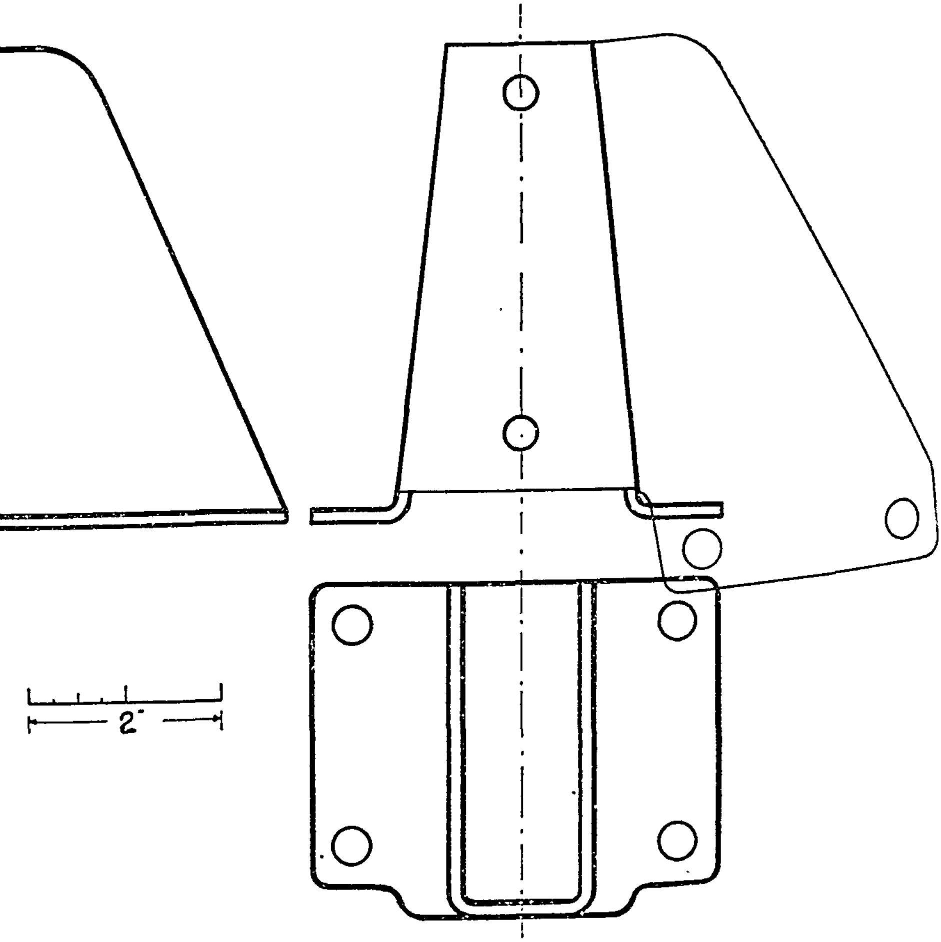


FIG. 38. A PRESSED STEEL BRACKET

CHAPTER IX

MISCELLANEOUS DATA

ASSEMBLING, fitting and erecting may all be analysed into constituents. There are, broadly, two classes of assembly work, one in which simple components are secured together to make a *sub-assembly* or *unit* and the other in which these units are finally built up together. Fitting roughly corresponds with unit assembly and erecting with final assembly. In intensive assembly no adjustment of the parts by filing or scraping is permissible, but fitting implies that such adjustments, to make better fits, are necessary. When adjustments have to be made it is impossible to forecast operation times until their extent is known. In a works where the machining is done well precedents may be established from which the probable time for future work, allowing for adjustments, can be estimated. But the records should preferably be based on constituents, not on the overall times of complicated processes.

The first requisite for any assembling or erecting operation is an accurate list of the component parts. This is not always readily obtained, drawing office lists often being unreliable. For assembly work the best way to ensure that such a list is available is to make the assembly complete and perfect, then to take it to pieces again and amend the part list as requisite by reference to the laid-out parts. It is not sufficient for a bolt or spring washer to be listed merely as such: the list should state which bolt the washer is associated with, and the components which the bolt secures together.

When the assembly is being carried on in the first place a record should be made of desirable modifications to sizes or limits, and the drawings altered. If the perfect components are re-assembled under proper conditions the

time taken will be a basis to establish a fair piece-work price for the work when all the supplies are correct. Until that state is attained a temporary time should be arranged. If adjustments or rectifications are made during assembly the process will probably take two or three times longer than necessary.

Assembling cannot be carried on efficiently without adequate supplies of components arranged conveniently in bins or trays.

Light assemblies can be made to flow along lines either with the aid of conveyors or by handing on from one operator to the next. It is essential to balance the work equally among the operators or the rate of flow will be unsatisfactory. Group payment (this, by the way, is not a new but an old system) is suitable for line assembly, but experience proves that greater efficiency can often be got by arranging to pay the men more individually. Conveyors stimulate management as well as operators. Yet it is easy to install them where they are a handicap. They are best employed where a fairly constant output is desired for a long period.

When planning for a conveyor the first consideration is the output desired. The number required divided into the number of minutes worked per diem gives the unit time; and the assembling process must then be divided into operations each of which will take, as nearly as possible (but not more than), that unit time. The number of stations for operators corresponds with the number of operations. There are generally more operators than would be needed under ideal conditions without a conveyor owing to the impossibility of making each operation the exact unit length; yet the output per man-hour is increased by a conveyor because it is more uniform and adequate supplies are forced.

The length of the conveyor will depend on the space available, the number of operators, and the distance between them. It may be possible for work to be carried

on on both sides of the conveyor. This is equivalent to combining the operations. For small light work 3 feet distance between the operators (on one side) is often enough. But it is not a good plan to cramp the space: there should be, if possible, a foot or two of idle space between adjoining stations to allow for occasional encroachment. Such idle spaces render a longer conveyor necessary but do not affect the total assembling time. This depends on the conveyor speed. The speed of the conveyor should be such that the length travelled in the unit time is that assigned to one operation (excluding the idle space, if any). When lengthy operations cannot well be subdivided they must be provided with stations suited to the number of operators required at them to preserve balance.

Suppose it is desired to assemble 100 machines in $8\frac{1}{2}$ hours on a conveyor which can be as much as 90 feet in length. This gives a unit time of

$$\frac{510}{100}$$

or practically 5 minutes. The whole assembly, *without a conveyor* takes, say, 72 minutes, including an adequate fatigue allowance—usually $12\frac{1}{2}\%$ for light and 15% for heavy work; but these amounts are not enough if the machine work is faulty, for fatigue is here understood to include contingencies. When the process is analysed for being worked on a conveyor it is found that, say, 16 operations are necessary, the unit time being 4·8 minutes, and the total 76·8 minutes. Also it is found that 10 operators should work on one and 6 on the other side of the conveyor; but of the 6 it is necessary for 2 to be free from interference by opposite operators. Hence the conveyor must contain the length necessary for 12 operations. If the length of the assembled machines is 3 feet and a space of 3 feet is allowed between them to permit working at the ends (this space, of course, depends on the circumstances—sometimes turntables on the conveyor are practicable), the machines will be at intervals

of 6 feet along the conveyor. But since an idle space of, say, 1 foot is to be allowed, the operators' stations will be at intervals of 7 feet. The available space of 90 feet is more than sufficient for 12 stations but it might be advisable to use it all in case, at a later date, a modification of the machine should render an extra operation necessary.

Since the time unit is 4·8 minutes and the machines are at intervals of 6 feet the speed of the conveyor must be 6 feet in 4·8 minutes, or $1\frac{1}{4}$ feet per minute. After some practice this speed could probably be increased owing to lessened fatigue. When reckoning the operation time for conveyor work the fatigue allowance may be $7\frac{1}{2}\%$ for light and 10% for heavy work. In addition there must be about 5% reserve operators to replace temporary absentees from the line. These reserve operators should be provided with stand-by work such as rectification.

Fitting and assembling operations commonly met with may have times assigned to them based on the data which follow. Fatigue, tool attention, etc., are allowed for in the rates unless otherwise stated but handling the work is extra. Removing machine marks by filing and scraping, 15 seconds per square inch for cast iron and 20 seconds for steel. Deduct 25% for narrow surfaces of less than, say, $1\frac{1}{2}$ inches wide.

Scraping a flat surface. On a cast iron plate allow 40 seconds per square inch if a 0·002 inch feeler will barely enter between the plate and a straight edge at any part at the start. Add 20 seconds per square inch for each 0·001 inch additional error. For a surface of less than half a square foot allow 30 seconds per square inch. If two faces are to be scraped true and parallel or square with each other calculate as above and add 50% for every 0·003 inch relative error at the start. The fatigue allowance is included in these times.

Bearings. Scraping and bedding times depend on the accuracy of the previous machining. For bedding test

bars in cast iron housings allow 2 minutes per square inch unless a crane is required, when 3 minutes is an average figure. Similar bedding in aluminium housings take 1 minute per square inch.

Scraping brass bearings to shafts 1 minute per square inch.

Scraping white metal to shaft 40 seconds per square inch.

The last two times are for scraping only, no handling. An approximate formula for scraping and bedding, including all handling, is: Time in minutes $= 4 \times$ diameter in inches $\times$ length in inches, for white metal bearings. For brass bearings replace 4 by 6. All these times can be reduced when the previous machining has been well done, as it usually is in intensive manufacture, but not for general production. Allow 15% fatigue on the above times.

Light assembling data. Allow 6 seconds for taking up the first piece (usually the largest) and placing it in position in the assembling fixture. Secondary pieces will need about 2 or 3 seconds each to place in position unless intricate manipulation is required. If a secondary piece is a good fit in a hole or register allow 5 seconds.

Small screws used for fastening can be inserted and started in 6 seconds. The whole operation of inserting and making tight will take 12 seconds with an Archimedean, 15 seconds with a ratchet, and 18 seconds with an ordinary screw driver. These times allow for picking up and replacing the driver. Screws of $\frac{1}{4}$ inch or $\frac{5}{16}$ inch diameter will need 30% longer. Long screws or bolts which thread through several pieces take longer to insert. If a nut is used add 6 seconds each if a driver is used with a box spanner. An ordinary spanner will increase the time by yet another 6 or 8 seconds for each nut—if conditions are favourable. Nuts must be easy fits or the times will be much longer.

Inserting and opening small spilt pins take 20 seconds

each. Studding with a stud box takes the same time as inserting screws with the respective drivers. Groups of small studs can be inserted and secured with power drivers at the rate of 5 a minute. Nuts on studs take about as long as inserting and securing screws of corresponding sizes. Fatigue is allowed for in the above times.

After each assembly operation some time is spent in overlooking the whole to make sure nothing has been omitted and to effect adjustments—not in size, but perhaps in spring tension, or to test working fits, or make alignment or inspect finish in case a part has got blemished during the process. This overlooking time must be allowed for by judgment and should not be stinted. It is better for a defective part to be replaced early rather than late in the process, and cheaper to train observant operators than maintain an army of inspectors.

Riveting is often done in a press. A slow action press is best—the rivet heads are less crystalline if made to flow slowly. The best work cannot be done in a press unless a compensating device ensures equal work on each head when several are formed simultaneously. With single riveting on a power hammer most of the time is spent in assembling and handling. Machine output can occasionally be increased by arranging operators in groups, some to assemble and one to rivet. More usually one operator assembles and rivets. 5 or 6 seconds will be spent in placing the work in position and forming each head. Assembling and rivet insertion may be estimated on the lines indicated above. An average basic time for simple light work assembled and riveted by one operator is 15 seconds for each rivet. Machine setting is, of course, extra. Small rivets up to $\frac{3}{8}$ inch diameter may be riveted hot with a pneumatic hammer at the basic rate of 3 a minute by a gang of 3 operators, a youth for heating and two for riveting. This rate does not include assembling the parts. Actually a nest of rivets close together can

be riveted at the rate of 7 seconds each, but there are various small incidentals, and the basic rate includes 20% fatigue. Larger rivets are associated with heavier tools and greater distances to travel. The pneumatic riveting of larger rivets by groups of 3 operators may have average basic rates per rivet of

30 sec.	for	$\frac{1}{2}$ in. dia.	rivets
40	,,	$\frac{3}{4}$ in.	,,
50	,,	$\frac{7}{8}$ in.	,,
60	,,	1 in.	,,

If there are temporary securing bolts to remove, an extra operator is needed. For awkward positions more time must be allowed. Hydraulic riveting takes about the same time as above but needs also a crane and a crane driver. Assembling parts or drifting holes is extra and either extra help or more time must be allowed.

Guillotines. Two operators per machine. Allow 3 minutes for setting stops. The first cut across a sheet takes 15 seconds for 16 S.W.G. and under, and 25 seconds for sheets up to $\frac{1}{8}$ inch thick. If the sheet is then fed to stop 3 seconds, and 5 seconds suffice for successive cuts on thin and thick materials respectively. If the sheet is dropped and picked up again allow as for the first cut unless the size is reduced so that handling is easy. Allow 20% fatigue extra. Each man will be occupied for the given times.

Rotary Shears. For average work the constituents are—

Pick up sheet—from 3 sec. upwards according to size
Lay on template—from 3 sec. upwards according to size
Mark off—from 2 sec. per foot of periphery
Remove template—from 2 sec. upwards
Transfer sheet to machine—according to distance and size
Cut—see under
Lay down blank—3 sec.
Dispose of swarf—from 2 to 5 sec.

The average rate of cutting is

12 ft.	per minute	up to	18 S.W.G.
9	,,	,,	14 S.W.G.
6	,,	,,	8 S.W.G.
4	,,	,,	$\frac{1}{4}$ in. thick

Allow 15% fatigue. Two operators or more are required for work of large area. Large pressings are often trimmed by band-sawing. The cutting rate is 10 seconds per foot up to 18 S.W.G.

Bending and Folding. On the average the basic time may be $\frac{3}{4}$ minute per bend. This includes marking a line on the work to position it in the machine.

Spot Welding. The actual welding time is scarcely considerable in comparison with assembling and handling. It varies from about 0·5 second for thin sheets up to 5 or 6 seconds for each spot, when the added thickness is $\frac{1}{2}$ inch. For rough estimates allow 10 spots per minute. This is an average rate for joining thin mild steel sheets and includes assembling and all other incidental work. More accurate estimates can be based on the assembling time plus 2 seconds a spot for 18 S.W.G. sheets and under, 3 seconds for an added thickness of $\frac{5}{32}$ inch, 5 seconds a spot for an added thickness of $\frac{1}{4}$ inch, and 10 seconds when the added thickness is $\frac{1}{2}$ inch. Fatigue allowance 20% extra. The above figures are probable minima. More handling time is necessary for unwieldy components. Trimming the copper points is included in the fatigue allowance.

Oxy-acetylene Welding. The average rate for girls tacking and welding sheet metal components up to and including 22 S.W.G. is 8 feet per hour. Men on 16 S.W.G. sheets can deal with 6 feet per hour. These rates include assembling the parts, fatigue, and other allowances.

If the tacking and welding be separated add to the assembling time, for each separate tack, the time required to weld $\frac{1}{2}$ inch length as shown in Fig. 39. This allows for intermediate handling of the blowpipe and the starting heat.

Short welds should be rated similarly. Allow 25% fatigue. Fig. 39 shows graphically the rate of welding for sheets of various thicknesses, also the amount of oxygen (= acetylene) and the diameter and length of welding

wire required per foot run. These, like the charted data immediately following are only a rough guide. At

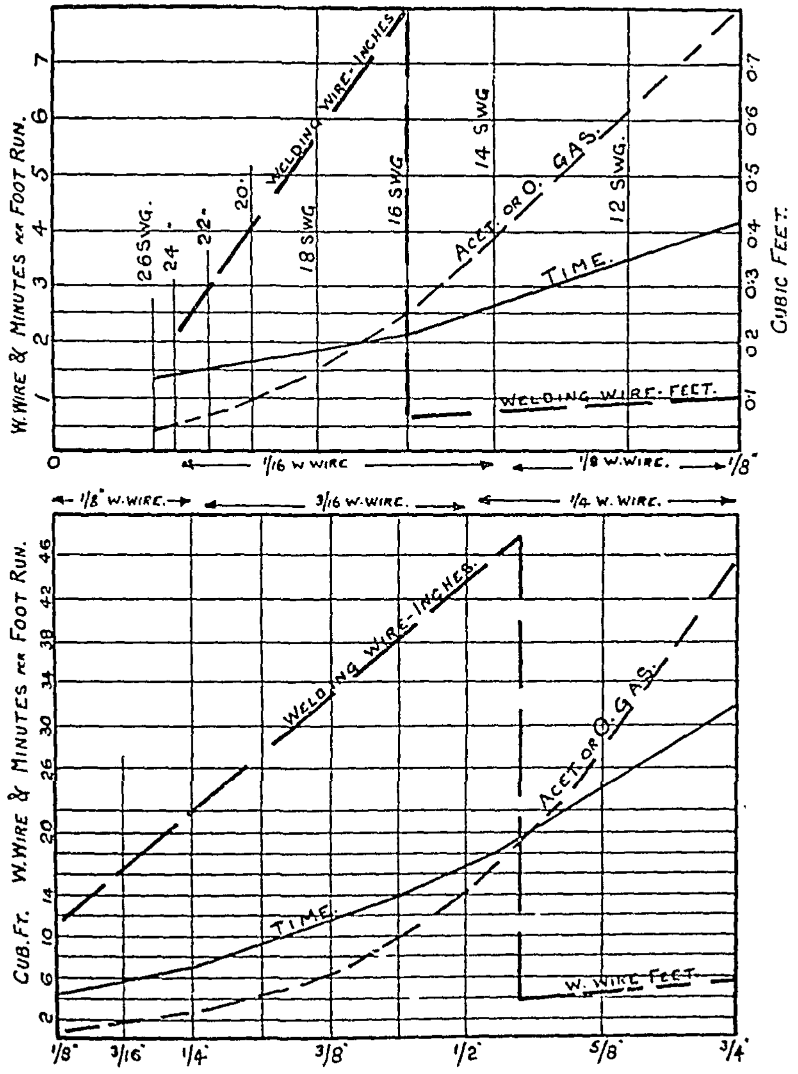


FIG. 39. OXY-ACETYLENE WELDING

atmospheric pressure it takes 11·2 cubic feet of oxygen and 13·6 cubic feet of acetylene to weigh 1 lb.

Oxy-acetylene Cutting. Incidental work must be judged by the circumstances. Cutting speeds and the amounts

of the gases consumed are shown in Fig. 40. The preparatory heating time may be allowed for by adding to the length to be cut the thickness of the plate and an additional 4 seconds to the calculated time. Where there are sharp bends allow 50% extra time. The fatigue

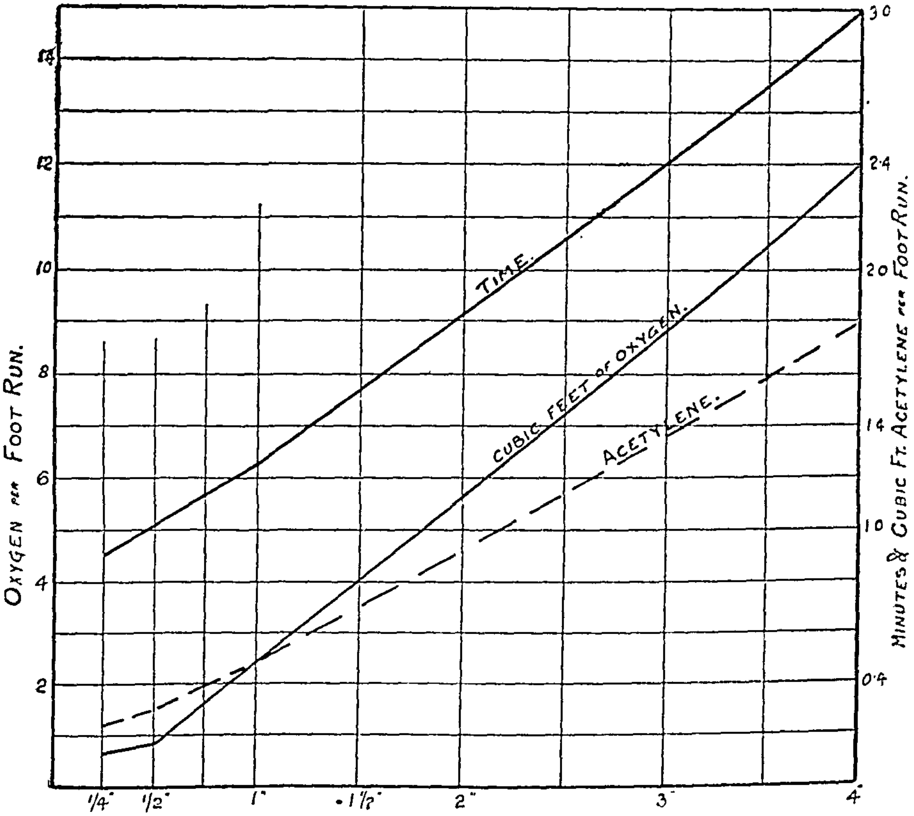


FIG. 40. OXY-ACETYLENE CUTTING

allowance may be, on the average, 25%. When the process is automatic 15% is enough.

Butt and Flash Welding. Assembling the parts in the machine resembles jig loading and must be estimated similarly. Allow from 2 to 5 seconds per weld for machine manipulation according to massiveness. Welding times in seconds per weld are shown graphically in Fig. 41, which also indicates the approximate amount of power used. The power consumption is heavy for large welds and must

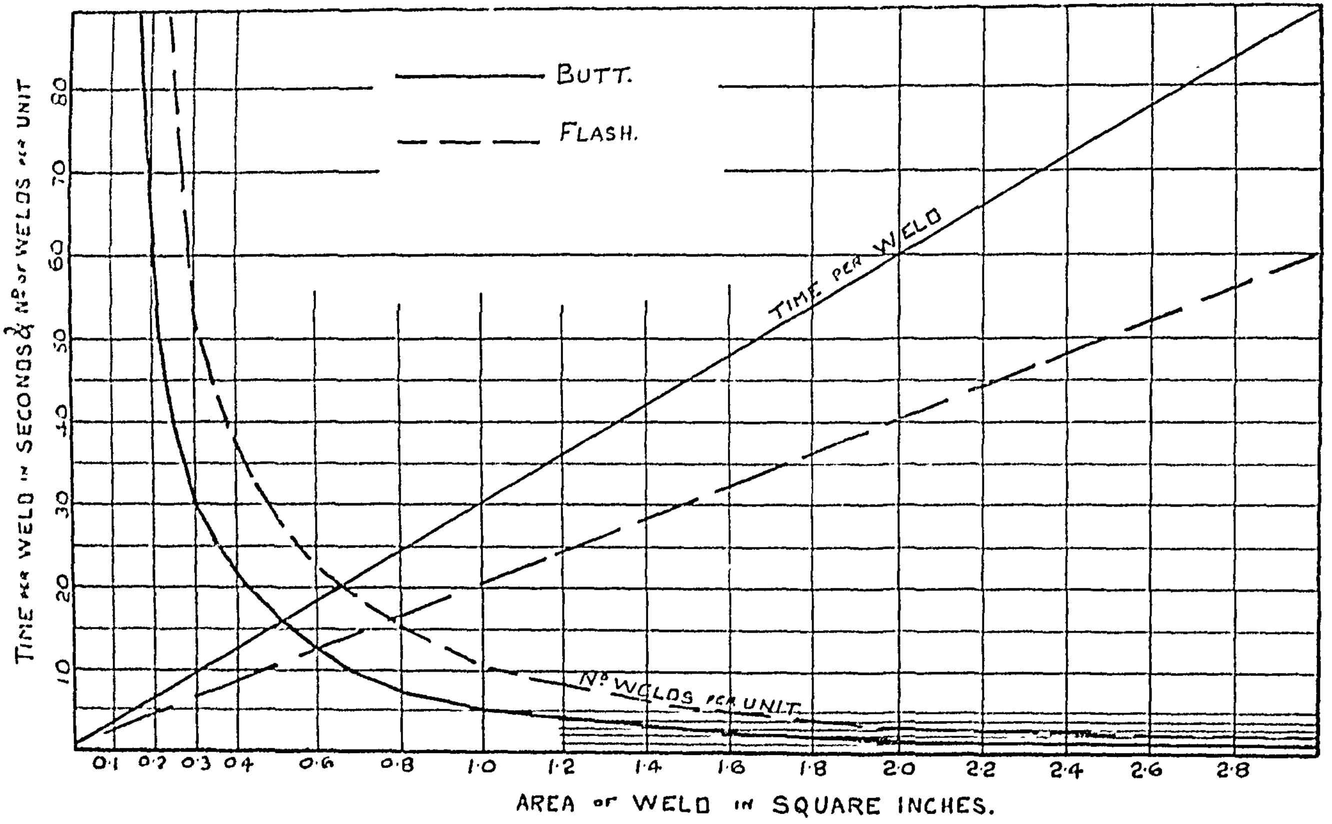


FIG. 41. FLASH AND BUTT WELDING

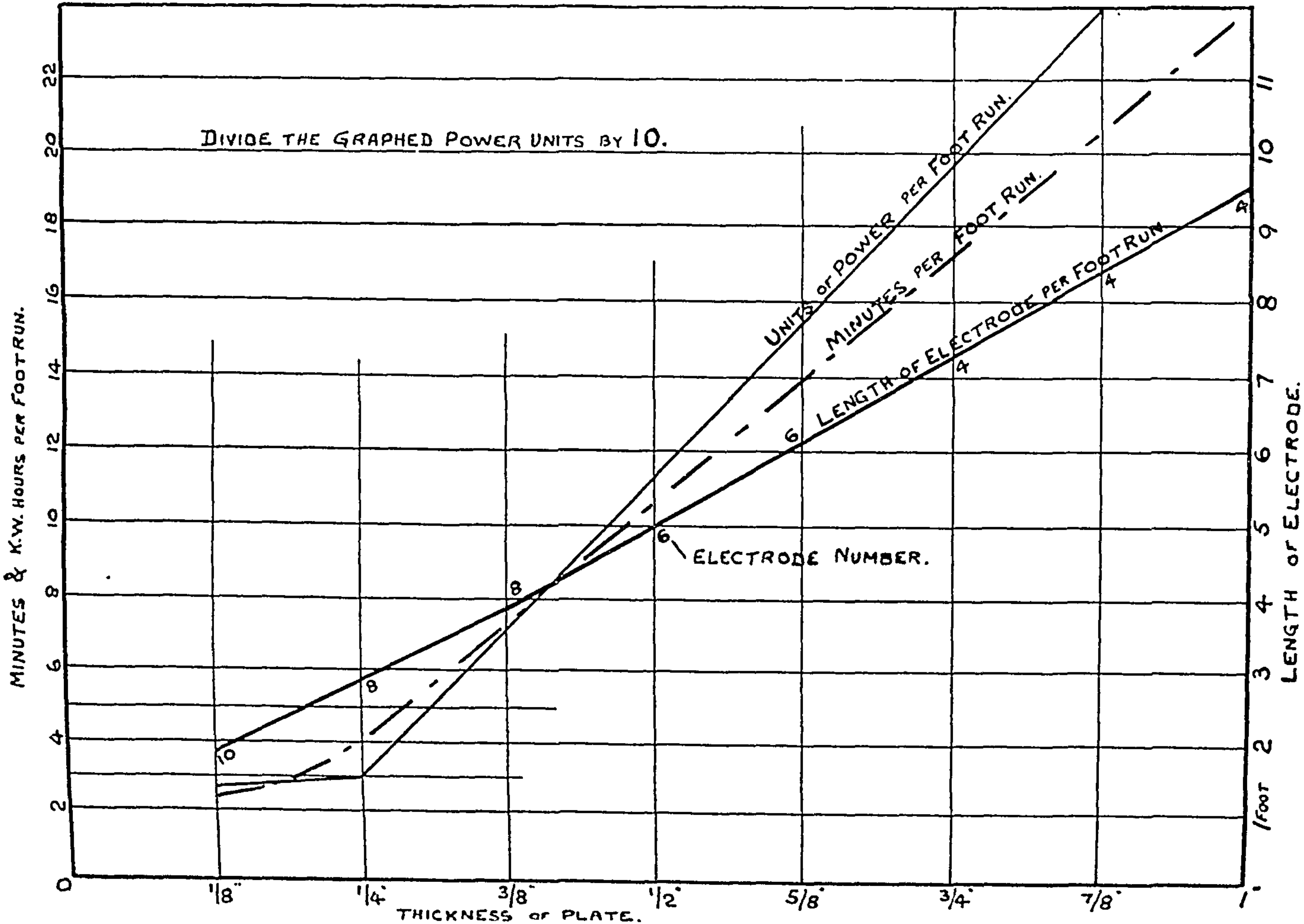


FIG. 42. ARC WELDING

be reckoned in the process cost. The value of the material burned away is also considerable. Fatigue allowance 20% extra.

After welding it is usually necessary to remove the excess metal at the junction by filing, grinding or turning.

Arc Welding. Preparation and assembling are extra to the times obtained by using the graphs in Fig. 42. Allow 30% fatigue. The curves also indicate approximately the indirect materials consumed.

Spraying Enamel. One sprayer can spray large area work at the rate of 10 square feet per minute—much faster if the relative motions of man and work can be made rapid enough; as in most other processes manipulation is the deciding factor, not machine capacity. When the work is placed in position by the sprayer allow the necessary time for that and any other business (such as carrying to and suspending in oven) plus 12 seconds per square foot for coating articles of about 8 or 10 square feet area, which permit easy access to the spray, and up to 30 seconds per square foot for small articles, of which several can be sprayed simultaneously on a turntable.

Masking is extra. Allow 25% fatigue when the operator is liable to get badly soiled and 20% otherwise. Replenishing paint supplies is covered in these allowances.

The covering power of enamel depends on its nature. An average figure is 250 square feet per coat per gallon of sprayed mixture (enamel plus thinnings) for large area work. On small components much of the spray misses the target and one gallon may suffice for only 150 square feet. All of the above figures are subject to a considerable modification in differing circumstances. Evidently the process rate per hour (see Chapter XI) can amount to a high figure. For example the details may be—

	s.	d.	
Wages	1	6	
2 gal. of enamel at 6s.	12	–	
Overhead charges	2	6	
Process rate	16	–	per hour

Dip Enamel. The process may be analysed in exactly the same way as spraying. When quantities are small the labour constituents are

Dip
Hang to drain
Transport to and suspend in oven
Remove from oven

When a conveyor is used they become

Dip
Suspend on conveyor
Remove from conveyor

In both cases the circumstances must be studied before a time can be given. It must not be forgotten that the capacity of the oven and the conveyor may be deciding factors.

Flatting for Second Coat of Enamel. Actual time equals $1\frac{1}{2}$ minutes per square foot, including 20% fatigue and personal cleaning allowance.

The preparatory cleansing of the work with turpentine (or by other means) before enamelling is a considerable item. An average time is 30 seconds per square foot for greasy work cleaned with turpentine and rag. This allows also for incidental transport, which is sure to be necessary.

Polishing. The actual time for polishing brass may be based on 1 minute for 8 square inches of surface when the surface is smooth and there are no hollows difficult for the mop to reach. If the surface is rough to start with 1 minute for 5 inches will be about right. When there are hollows the time must be increased, perhaps 50%, perhaps 100%, according to the accessibility.

Similarly for steel or cast iron the time will vary on plain work from 3 to 5 square inches per minute according to whether the surface is rough or smooth to commence. For rough polishing allow 50% of these times.

After nickel plating the surface may be repolished a

the rate of 24 square inches per minute irrespective of what metal the nickel is deposited upon, but subject to an increase of time for irregular surfaces as before.

After chromium plating polishing will take 1 minute for 48 square inches when the surface is plain.

Fatigue, amounting to about 20%, is a necessary extra to the above times. For very small articles which require proportionally rather more handling than larger ones and which get uncomfortably hot during the process a small addition should be made—say 5% to the basic time.

Nickel Plating. It is not possible to give reliable figures, but as a guide for estimating the process cost of nickel plating may be taken as 4d. per square foot when it is done in a still vat.

Chromium Plating. The process cost of this, plus that of the preparatory coat of nickel, may be estimated at 7d. per square foot.

Shot Blasting. 100 square inches a minute is an average rate for blasting small tools and miscellaneous work. Plain work of large area can be done at the rate of 1 square foot per minute. This includes removing heavy scale, and both rates can be maintained, i.e. they include fatigue and other allowances. The process is extremely unhealthy and automatic plants which free operators from danger to lungs should be more rapidly developed. It is found that two operators working in the cell alternately for periods of about ¾ hour, can do nearly twice as much work as one man in the cell the whole time. The outsider can prepare work for his mate as well as recuperate.

Heat treating steel. It is not worth while distinguishing between different treatments with great nicety. Annealing or normalizing may roughly be taken as equivalent in cost to the two heats which are given to obtain the required hardness or strength. The process cost for the pair of heats is about 2/- per cwt. when the furnaces are worked night and day regularly. In the average engineering

works 3/- per cwt. is a reasonable figure. The process cost includes fuel, wages, upkeep, and all other oncosts (see Chapter XI). Where furnaces are not worked continuously the expense may be nearly doubled.

Carbonizing or Carburizing costs about 8/- per cwt. under the most favourable conditions. 10/- per cwt. may usually be considered satisfactory, except for large scale plants; but for small plants, worked intermittently, 14/- or 15/- per cwt. is a more likely process cost. Of course the depth of penetration required affects the figures: the above apply to depths averaging $\frac{1}{32}$ inch. The expense of the two heats and quenchings after carbonizing is included in the cost.

Nibbling is quicker and better than oxyacetylene cutting for thin sheets—less than $\frac{5}{16}$ inch thick—and is applicable to materials other than mild steel. Allow 30 inches per minute for sheets less than $\frac{5}{32}$ inch thick, and 20 inches per minute for thicker ones. These rates are for one cut. Marking off or attaching a template is extra.

Small die-castings in a zinc base alloy are becoming very popular for such components as covers, frames, ornaments, and brackets. Provided the cost of the dies can be distributed over sufficient production to justify the initial outlay, these castings are preferable to brass (unless there is soldering to be done) and much cheaper. Small die-casting machines making components weighing a few ounces can be operated at the rate of 150 shots per hour on a day's run. There may be one or several components per shot, according to requirements and machine capacity.

CHAPTER X

PROCESS LAYOUTS AND COST ESTIMATES

It is useless to go to the expense of preparing master process layouts if they may be ignored in the workshops. This implies that they must be competently made. The planning engineers should be men specially trained and gifted. Foremen and superintendents are, or should be, chosen mainly for their administrative ability. Few of them have had the right training and experience to qualify immediately as successful planning engineers; but, by a confusion of thought, it is commonly assumed that because a man has had a long and successful experience in shop management he must necessarily be also a master of technique. In practice a man can manage a shop successfully if he can control men and has the organizing ability to keep production flowing. He need not be an engineer in the technical sense.

A planning engineer should have had a good general education. He must have, at least, sufficient knowledge of pure and applied science to understand what he is about. Several years' workshop experience are essential, of which a large proportion has preferably been spent in the tool room, and some in inspecting and testing. After this he should have had a year or two in a good jig and tool drawing office. Then he will be ready to take up planning.

To ensure that layout instructions are followed, piece-work pay should be withheld if work is carried out contrarily; the contract with the operators should contain a clause enabling this to be done. Yet it must not be understood that suggestions for alternative methods, whatever their source, shall not be considered and adopted if they have merit. The majority of suggestions fail because they are based on imperfect understanding of all

This forms a frame, to be improved as further consideration shows to be desirable, about which the master layout may be built later. The proper layouts to send to the cost and wages offices are copies of the rate fixers' or shop layouts. These represent the actual procedure and may be used as the rate fixers' contracts with the operators. The times estimated by the planning engineer will sometimes exceed and sometimes fall short of those contracted by the rate fixer. The divergence should be trivial and the result may be considered satisfactory when the sum of the contract times is not greater than the estimate. Should there be any great adverse difference, say more than 10% in any of the operation times, the rate fixer should not fix the price before the planning engineer has investigated and, if possible, improved the conditions so that the estimated time shall not be exceeded. It is permissible to arrange a temporary price or time which will be reconsidered at frequent intervals until either conditions are made better or it is decided to stabilize them. Such contracts must be plainly marked "Temporary" or "Provisional" so that no doubt or argument may arise later.

Planning is usually done more efficiently by properly qualified specialists than by foremen, ratefixers, superintendents, or tool designers. It is expensive, but not an extra expense, because the work has to be paid for in any case. It pays to have it done well.

Even for small-quantity production a few formally prepared process layouts will save much time and scrap in the case of the more difficult components. Piece-work is recommended, too, not so much to hurry the men as to stimulate or assist the management. This applies to tool-rooms and experimental shops as well. It has even been successfully applied to typewriting.

A capable planning or efficiency engineer can give useful service by advising on the purchase of plant, guiding tool design, improving shop conditions, and in

many other ways, besides preparing process layouts, although it is through them that most of his advice or instructions are conveyed.

The art of making process layouts can be acquired only by practice. Every one represents a great deal of thought, which, however, generally proceeds along on

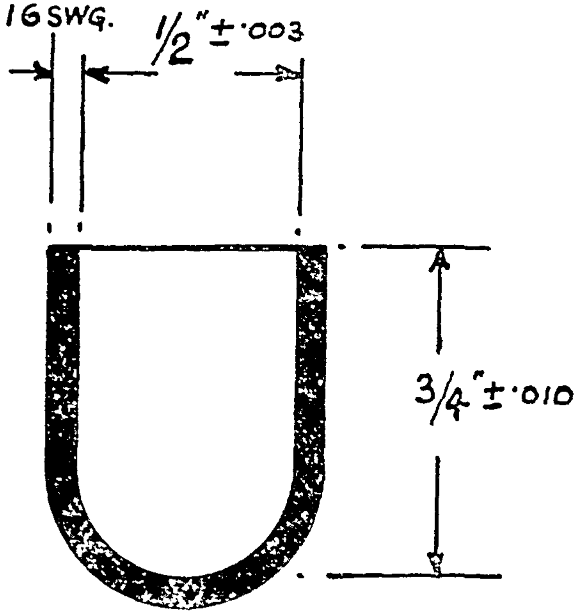


FIG. 43. DRAWING A M.S. CUP

main track. The nature of this track will be indicated by the examples.

A skeleton layout is to be made for producing the mild steel cup shown in Fig. 43.

The first question is "How many?"

It looks like a press job, considering the material, but a few could be turned from bar or spun from sheet. Let the quantity be 10,000. It is then definitely press work and would be bought finished if no suitable presses were available.

What is its function? Alternatively, what degree of accuracy or finish is desired? The drawing is clear; limits are specified.

A single action drawing press will be suitable. The end must be trimmed after drawing as it will be ragged. The diameter of the blank may be got by the method described on page 182, or from the formula—

$$D^2 = 8\,r\,(h + \tfrac{1}{8}),$$

where D = diameter of blank,

r = radius of finished shell, measured inside,

and h = depth of shell, measured inside.

The $\frac{1}{8}$ inch added to h is to allow for irregularities and trimming. For long shells of small diameter the wire method is not so well adapted but it can give satisfactory results if the work is done carefully—preferably on a drawing twice full size, the suspension being by means of a thin thread hitched to the wire to prevent slipping.

From the formula

$$D^2 = 8 \times \tfrac{1}{4}\,(\tfrac{3}{4} + \tfrac{1}{8}) = 1\tfrac{3}{4}$$

$$D = 1{\cdot}32$$

It will be near enough to take $D = 1\frac{5}{16}$ inches, the $\frac{1}{8}$ inch allowance being slightly larger than necessary. If blanked singly from strip the strip will be $1\frac{7}{16}$ inches wide.

The blank is thick in proportion to its diameter, hence the first draw can bring its diameter (measured inside) to 30% less than $1\frac{5}{16}$ inches or 0·918 inch diameter. The arithmetic may be set out concisely thus—

Blank dia.	$1\frac{5}{16}$ = 1·312
1st reduction 30% . .	·3936
Cup diameter . . .	·918
2nd reduction 30% . .	·2754
Cup diameter . . .	·643
3rd reduction 20% . .	·1286
Cup diameter . . .	·514
4th reduction 20% . .	·1028
	·411

Since the 3rd reduction results in a cup so near to the desired size the first three reductions could be slightly increased with drawing material of good quality. Then

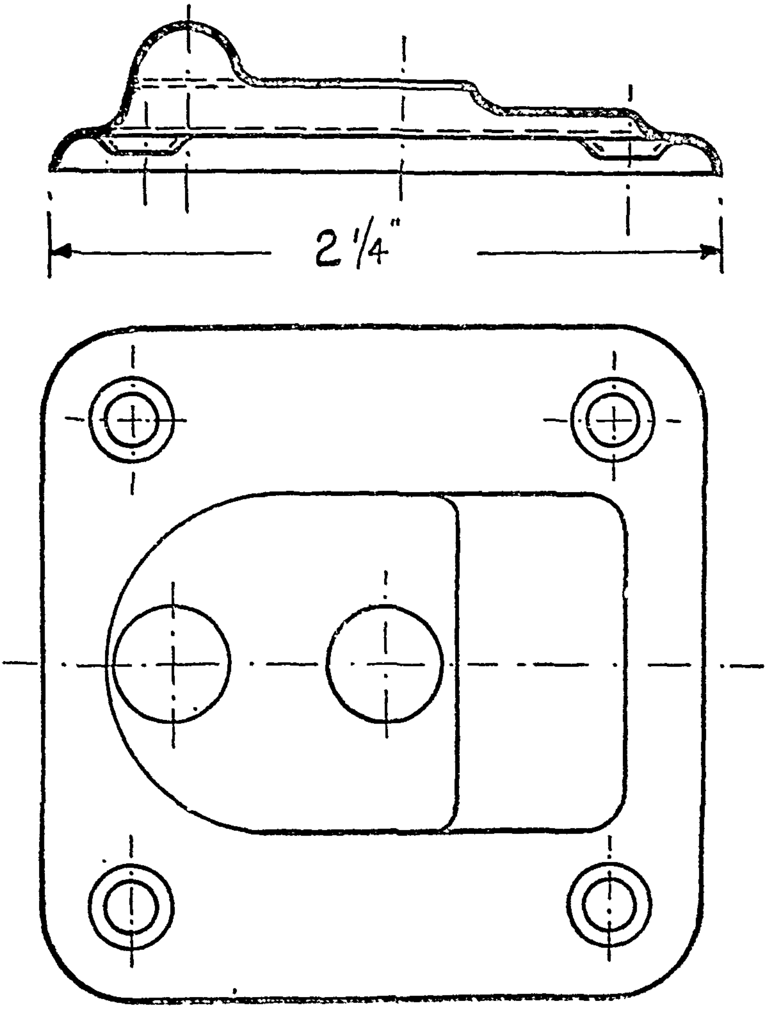


FIG. 44. RAISING A SMALL BRASS COMPONENT

three draws would suffice. Alternatively, four easy draws could be retained. Assume four draws, the diameters being $\frac{15}{16}$ inch, $\frac{11}{16}$ inch, $\frac{9}{16}$ inch, and $\frac{1}{2}$ inch. The even sizes might enable stock tools to be used. In some

districts single action drawing of this kind is termed *raising*. Annealing will be necessary before every draw except the first.

The skeleton layout can now be written down, and later, the basic times (or P.W. times if preferred).

			Minutes %
1.	Shear 16 S.W.G. strips $1\frac{7}{16}$ in. wide 72 in. long	Guillotine	20
2.	Blank $1\frac{5}{16}$ in. dia.	Press	3·7
3.	1st draw $\frac{15}{16}$ in. dia.	Press	11·7
4.	Anneal		
5.	2nd draw $\frac{11}{16}$ in. dia.	Press	11·7
6.	Anneal		
7.	3rd draw $\frac{9}{16}$ in. dia.	Press	11·7
8.	Anneal		
9.	4th draw $\frac{1}{2}$ in. dia.	Press	11·7
10.	Trim to length and burr	Capstan	25

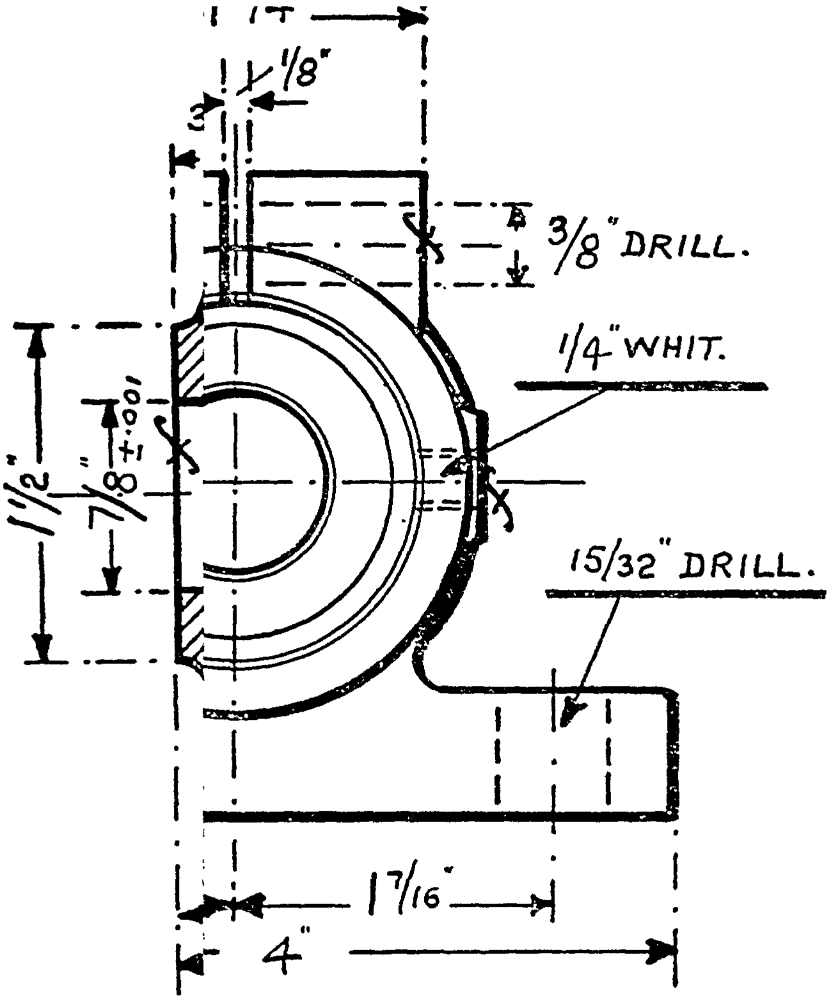
Setting-up times are not included

Unless the operation times are given on the layout, much of its value is gone. It gives, then, practically no information which will be useful to ascertain the requisite plant capacity.

The actual drawing press operation times will be about 5 seconds (with a press making 30 strokes per minute) but the fatigue and tool allowance add another 2 seconds to this. It is important to remember that the guillotine time for operation 1 is per strip containing 50 blanks. Annealing time can be given for the handling involved but more usually a tonnage basis is used for payment.

In the next example (Fig. 44) the shape of the blank must be found by trial but its size may be obtained approximately by measuring with raffia round the inside, leaving out the small dome because that will draw the metal thin locally and scarcely affect the size of the blank, though it may increase the bight by a small amount on the centre line.

It follows that a strip $2\frac{3}{4}$ inches wide by 72 inches long will make 26 blanks.


1/8"
3/8" DRILL.
1/4" WHIT.
1 1/2"
7/8" ±·001
15/32" DRILL.
1 7/16"
4"

		Minutes %
1. Shear 20 S.W.G. strips $2\frac{3}{4}$ in. $\times$ 72 in.	Guillotine	20
2. Blank and raise the centre . .	Press	9
3. Trim and pierce	Press	15
4. Finish, raise, and press countersink .	Press	11
5. Polish	Mop	100
6. Nickel plate	Vat	Process
7. Polish	Mop	35
8. Chronium plate	Vat	Process
9. Polish	Mop	18

Setting up is not included

In operation 2 allow long feed and about 2 seconds per blank for removal since it cannot be pushed through. In operation 3 the trimmed swarf has to be cleared away, which accounts for the difference between this and operation 4.

In Fig. 45 is shown a component which can be produced in a variety of ways. The final choice will depend to some extent on the plant available and the planning engineer's personal preferences, but his line of thought will be somewhat as follows—

The quantity required is 20,000, at the rate of 500 a week, therefore it will pay to tool the job well.

Cast mild steel is specified as the material. Would stampings be cheaper? No, for they would be solid and waste material and time, although cheaper per pound weight.

Should the $4 \times 1\frac{3}{4}$ flange be machined first and the boring of the long hole follow? No, it would be easier to complete the hole first and locate subsequent operations from that; although the flange is a fair size, the component could be better held in chuck jaws for the long hole, and the fixture to locate from that while machining the flange would be simple and rigid.

The $1\frac{1}{2}$ inch diameter boss requires facing on a drilling machine, a lathe, or by milling. The $\frac{3}{8}$ inch diameter hole through the boss $1\frac{3}{4}$ inches long should be done before the gash is cut. Hence the operation list will be, tentatively—

(1) Bore, face and screw long hole.

(2) Mill 4 × 1¾ flange.
(3) Face 1½ inch diameter boss.
(4) Drill all the small holes.
(5) Pinface small bosses and countersink all tapping hole.
(6) Tap 2 holes.
(7) Saw ⅛ inch gash.
(8) Burr (or fraze) as required.

For estimating the probable cost of machining this list is near enough; it covers the work to be done, although perhaps not in the correct sequence or in the most economical manner.

What kind of machine shall be used for operation 1? An automatic turret machine would be best if it were not for the screw thread. If that must be dead true it ought to be chased before sizing with a tap, and that might require a hand operated machine. Moreover, gripping the thin shell would deform it and the screw would not be true when the component was released from the chuck. Perhaps it would be better to machine the flange first, after all. Besides, to locate for milling the flange off the ⅞ inch diameter and the screw would not be satisfactory, unless a rather special device were made, and it would need frequent renewal, for the thread has a fine pitch.

But further examination and enquiry shows that the screw will be quite satisfactory if only commercially accurate; moreover the 1½ inch distance dimension bears the limits ± ·010 inch. Hence the thread can be tapped without chasing first and a mandrel which fits its core diameter will be quite near enough to locate for machining the flange. Alternatively a register could be bored or turned at the end to facilitate this location. This could not be done without permission from the drawing office. Anyway an automatic machine can be used for the first operation.

The next problem is, how long will the operation take? For the rough estimate assume 80 cuts per inch for the boring feed and, to avoid niceties in allowing for the retard while rounding the end of the cam, take the length of travel to be an inch longer than reality. Cross-slide facing need not be taken into account in this example because the facing will be done during the boring.

There will be four turret faces available, the last being reserved for the tap. The first turret face can be used for drilling the $\frac{7}{8}$ inch hole to $\frac{13}{16}$ inch diameter; it will be already cored and the 80 cuts per inch will do.

There will be no time when making a quick estimate to study the speeds available on the machine, but reference to Table VI shows that under good conditions a $\frac{13}{16}$ inch drill will penetrate 1 inch in 15 seconds. In this case the distance to penetrate will be about $\frac{5}{8}$ inch but the speed will be low and 30 seconds will probably be required with the retard.

1st turret face	30 sec.

The second face can be used for rough boring all the diameters and facing the bottom end. The dimensioned length of the longest cut is $1\frac{7}{16}$ inch. To allow for inequalities and the lag at the end of the stroke this may be reckoned as $1\frac{7}{16}$ inch + 1 inch or, near enough, $2\frac{1}{2}$ inches. The 1 inch includes $\frac{1}{2}$ inch retard and $\frac{1}{4}$ inch at each end for tool overrun. At 70 feet per minute the r.p.m. will be about 150. It is as well to keep on the low side for the present purpose. The time will be $5/2 \times \frac{80 \times 60}{150}$ seconds = 80 seconds.

2nd turret face	80 sec.
3rd turret face	80 ,,

The 3rd face will repeat the second but take finishing cuts. For the 4th face the speed must be reduced to

about 30 r.p.m. Perhaps, the thread being fine, a collapsible tap can be used. The distance travelled may be taken as 2 inches and the time will be $2 \times \dfrac{20 \times 60}{30}$ seconds.

4th turret face	80 sec.
Indexing four faces	25 ,,
Loading, handling, and gauging . . .	90 ,,
Total F to F time	= 385 sec.

Tool and fatigue allowance should be about 40% considering the number of tools cutting together, and that it is not certain (since the whole position has not been studied) that the operator will be able to keep all his machines running fully. Hence the operation time will be 9 minutes.

The obvious way to machine the 4 inch × $1\frac{3}{4}$ inch flange is to face mill it. Should there be one cut or two? Should one or more be done at a time?

For the quick estimate, assume one on a simple fixture. It is ascertained that the base must be flat but need not have a fine finish, therefore one cut will suffice; but assume the moderate travel of 3 inches per minute. The distance to travel will be 4 inches plus the overrun, say 5 inches. Hence cutting plus returning will take practically 2 minutes. Similarly loading plus tool attention will amount to 1 minute, giving a FFT = 3 minutes. A suitable basic time will be $3\frac{1}{2}$ minutes.

A good way of facing the $1\frac{1}{2}$ inch diameter boss will be to hold the component on a fixture on a centre lathe. To ascertain the cutting time assume one cut at a very fine feed instead of two coarser cuts. The distance to travel will be, allowing for overrun, about $\frac{5}{8}$ inch.

Cutting time at 100 cuts per inch and 90 feet per minute speed

$$= \frac{\frac{5}{8} \times 100 \times 60}{240} = 15 \text{ seconds.}$$

It will be observed that the figures have been adjusted

slightly to simplify the arithmetic, which is quite justifiable in such cases. The basic time will be $1\frac{1}{4}$ minutes made up by—

Loading and handling	$\frac{3}{4}$ min.
Cutting	$\frac{1}{4}$,,
Tools and fatigue	$\frac{1}{4}$,,

The next business is drilling the small holes.
There are—

2 holes $\frac{15}{32}$ in. dia..	$\frac{3}{4}$ in. deep
1 hole $\frac{11}{32}$ in. dia..	2 in. ,,
1 hole $\frac{17}{64}$ in. dia..	$\frac{1}{2}$ in. ,,
1 hole ·339 in. dia.	$\frac{1}{2}$ in. ,,

Each hole, it will be noted, has an amount added to its depth to cover the drill point penetration. The total distance is $4\frac{1}{2}$ inches. The long hole will require withdrawals of the drill, so call the total distance of penetration 5 inches to allow for it. At 4 inches a minute the cutting time will be $1\frac{1}{4}$ minutes.

Loading	$\frac{3}{4}$ min.
Handling	$\frac{1}{2}$,,
FFT	$2\frac{1}{2}$,,
Basic time	3 ,,

Handling includes 4 drill exchanges and 3 jig turn overs.

Pinfacing and countersinking—

Load	$\frac{1}{4}$ min.
Pinface 6	$1\frac{1}{4}$,,
Countersink 2	$\frac{1}{4}$,,
Handling and gauging	1 ,,
FFT	3 ,,
Basic time	$3\frac{1}{2}$,,

Tapping—

Load	$\frac{1}{4}$ min.
Tap 2	$\frac{1}{4}$,,
Handling and gauging	$\frac{1}{2}$,,
FFT	$1\frac{1}{2}$,,
Basic time	2 ,,

Sawing $\frac{1}{8}$ in. gash—

Load	$\frac{1}{4}$ min.
Saw and wind back	$\frac{1}{2}$,,
FFT	1 ,,
Basic time	$1\frac{1}{4}$,,

A basic time of 2 minutes should suffice for frazing.

It will be noted that $\frac{1}{4}$ minute is the smallest fraction reckoned and that the constituents have been slightly varied for simplicity. For example, in sawing $\frac{1}{2}$ minute is probably too long for the cutting and so the wind back has been included. The estimator will have made scarcely any reference to tables—there is seldom time when quick results are wanted. It is essential, therefore, for him to know all the data by heart: he should know the times for all the constituents as given in the preceding tables and also those noted by himself, though this knowledge alone will not make him a competent estimator.

The above results may be summarized in the form shown below, which is a skeleton layout. If the time allowances or prices are given instead of the basic times, a copy of this layout may be used as a contract note for work done in the shops, as previously stated, if the rate fixer has settled with the operators.

Op. No.	Operation	M/c	Basic Time
1	Bore face and tap . . .	Auto	$2\frac{1}{4}$
2	Mill flange	Milling	$3\frac{1}{2}$
3	Face boss	C. lathe	$1\frac{1}{4}$
4	Drill small holes . . .	Sen. drill	3
5	Pinface and countersink. .	,,	$3\frac{1}{2}$
6	Tap	,,	2
7	Saw	Milling	$1\frac{1}{4}$
8	Fraze	Bench	2

To find the labour cost the piece-work times or prices must be calculated. The man who operates the automatic turret lathe will work a group of, say, 4 machines, and his basic time would amount to $9 \div 4 = 2\frac{1}{4}$ minutes. The sum of the times for all the operations equals $18\frac{3}{4}$ minutes. With 25% added for piece-work the total amount is $23\frac{1}{2}$ minutes.

Where the "cost of living" bonus has been merged into ordinary wages and ranks for piece-work, the value

in money of the $23\frac{1}{2}$ minutes is 5·0d. when the day-work rate is 50/- a week. Generally this bonus is separate. A day-work rate of 40/- plus 10/- would bring to the operator, for $18\frac{3}{4}$ minutes at time and a quarter (see page 15)—

$18\frac{3}{4}$ min. piece-work pay at 40s. day rate . . .	4·0d.
$18\frac{3}{4}$ min. at 10s. per 47-hr. week	0·8d.
Total	4·8d.

To simplify the arithmetic the estimator needs a table similar to those on page 15, but calculated as above with the "Cost of Living" bonus included. He will choose the wage rate which when applied to the whole of the operations, as in the above examples, will yield a labour cost not below what is likely to result in practice. The rate of pay may be variable but for much estimating there is no time for considering the operations separately and a fair representative wage rate must be assumed. It will not often be the average rate and can be arrived at only by examining the records of similar work done in the past.

The master process layout for the component is shown in Figs. 46 to 49. The left hand column contains all the necessary calculations, the time, in seconds, for each movement, and the total FFT. If the other matter is not self-explanatory the layout is a partial failure. It should be mentioned, however, that the speeds and feeds to be used in the first operation have been chosen from the possible ranges on the selected machines.

The key speed is that for tapping and this makes the boring speeds rather slow. The feeds, too, are fine, not on account of inadequate power, but because, as already mentioned, small cutters mounted in springy bars soon fail under heavy cuts. The original scheme is substantially adhered to but improved in detail and refined. The master layout sets a much higher standard of efficiency and shows the works exactly how to obtain it.

PROCESS LAYOUT.

MATL. Cast M. Steel. | PART No 971

DATE. 5/11/32 | TITLE: Anchor Bracket | SHEET No 1

No of SHEETS. 4

		OPERATION.	PLANT.	PLANT No.	OP. No LAB. CL. P.W.T.
		Receive in C stores. View			
		Set up M/C. and maintain.	XZ auto.	370	101
			Special jaws. 2 on cyl. 1 on base. Back ledge to set base.	T1356	D
			Pilot Bush	T1349	1·12 (8 r'd hrs)
	30	Chuck.			
	6		1st Turret Face.		1
$(\frac{5}{8}+\frac{1}{2})\frac{70\times 60}{120}$ Part of retard.	40	Drill 7/8" hole	13/16" 3 flute drill – short. Socket	Stock	B
	6		2nd Turret Face		2·35
		Bore 7/8" hole to 27/64"	Pilot boring bar with 3 tools	T1350	(4 m/c loss)
			Boring tool	·/1	
		C'bore 1½" dia. to size	C'boring tool	·/2	
$(1\frac{3}{4}+\frac{3}{4})\frac{70\times 60}{120}$	88	Bore 1¾" screwed dia. to 1²¹/₃₂".	Boring tool	·/3	
		Simul. with 2nd T. Face. R. face end of 2⅛" boss to 3¼" + 1/64" from ledge.	Rear Cross Slide. Standard tool post. Facing tool.	S92	
Total 450; 25% PH 112; 4) 562; 4 m/c 141 secs; T.A. = 2·35 mins	6		3rd Turret Face		
		F bore 7/8" hole to size.	Pilot boring bar with 3 tools.	T1351	
			Boring tool	·/1	
	88	Chamfer 1/32" at 45°	Chamfering tool	·/2	
		Bore screwed hole to 1·691/1·694 dia.	Boring tool.	·/3	
		Simul. with 3rd T. Face. F face end of 2⅛" boss to 3¼".	Front Cross Slide. Standard tool post. Facing tool	S92	
	6		4th Turret Face.		
$2\times\frac{20\times 60}{120}$	20	Tap 1¾" × 20 T.P.I full thread.	Special tap	T1352	
			Special relinquishing holder	·/1	
Gauge	15		Special Cam.	·/2	
FFT.	365		L Plug gauge 7/8" dia.		
			" " 1·691/1·694		
Tools 7½% on 296	22		1½" dia. × 3⅛" depth gauge		
Fat. + Cont. 17½%	63		1¾" × 20 T.P.I screw plug.		
Total	450				

FIG. 46. MASTER PROCESS LAYOUT. SHEET 1

MATL.

PROCESS LAYOUT.

PART No 971

DATE. 5/11/32

TITLE: Anchor Bracket.

SHEET No 2

No of SHEETS. 4

	OPERATION.	PLANT.	PLANT No	OP. No LAB. GR. F.W.T.
Time 30 25% PW 7.5 37.5	Set up M/C	Hor Milling M/C. Series fixture holding 4. Locate on vertical posts to cut 1·691/1·694" and 7/8" dias Clamp top down. Locate base on stops.	436 T1360	102 C 37·5
4) 284 45% 71 15% 11 82 25% 21 103 18 × 60 / 4 Return 0 3 3 270 2 284	Load and unload during cut. Wind table to clear and reset for each load. Mill base 1½" from centre one cut	Face mill 2½" dia arbor	Stock	2 C 1·7
	Set up M/C	Centre Lathe. Fixture to locate on dias as for op. 2. Support 7/8" end on centre. Swinging clamp to hold back	209 T1361	103 C 25·0
36 / 1.5 + 25% 2 × ½ × 52 × 60 / 300 and gauge 20 10 4 2	Load. Face 1½" boss to 3¼" long	Facing tool	S94	3 C 0·85
4 Spdl = 60 25% = 15	Set up M/C	4 Spindle Gang Drill. Fixtures described under spindles.	450	104 D 75·0
25 R&L 10 FFT = 90 15% = 15 114 25% 25 60/142 TA = 2·35 0 1 25 6 and change drills 11 6 R&L × 2 4 2	Load. Drill 2 holes 15/32" dia. Transfer component to next spindle Load — 3 jigs to be in use simultaneously. Drill 339 hole for 3/8 tap. Turn jig over. Drill 3/16 hole for ¼ tap. Transfer jig to next spindle	1st Spindle. Power feed. Jig fixed to table. Locate as previously but mandrel oval to let cam wedge bore against bush plate. 2 Spindle head. 2 drills 15/32" dia 2 sockets 2nd Spindle. Hand feed. 3 jigs. Locate as before. Quick change chuck. Twist drill. Holder. Twist drill Holder.	T1365 T1366 Stock	4 C 2·35

FIG. 47. MASTER PROCESS LAYOUT. SHEET 2

MAT'L.	PROCESS LAYOUT.	PART No 971
DATE. 5/11/32	TITLE: Anchor Bracket	SHEET No 3
		No of SHEETS 4

		OPERATION.	PLANT.	PLANT No	[illegible]
			3rd Spindle		
			Power feed		
	0	Drill $\frac{3}{8}$ hole halfway	Twist drill		
			Socket		
	2	Transfer jig to next spindle			
F.S.C. × 2	4		4th Spindle		
			Power feed		
	0	Drill $\frac{3}{8}$ hole to meet	Twist drill		
Return jig	3	halfway	Socket		
	09				
3 Spindles 45		Set up M/C	3 Spindle Gang Drill	510	105
25% 11			Fixtures described under		D
56			spindles.		56·0
			1st Spindle		
	5	Load.	Fixture bolted to table — a	T1369	5
Start 35 M/C	6		plate with 2 short $15/32$" dia pegs.		
F.S.C.	2	Pinface about $15/32$" dia holes	Special tool to clear cylinder	T1370	C
$\frac{3}{16} \times \frac{60}{2}$	6	reversing on fixture for 2nd hole.	Socket	Stores	
Repeat	19	Transfer component to			2·7
	19	next spindle.			
	1				
	25	Load.	2nd Spindle		
			Fixture similar to the 3 used	T1371	
			on op 4.		
F.S.C. × 2	4		Quick change chuck		
P.F. × 2	10	Pinface (exactly) for $1\frac{3}{16}$"	$3\frac{1}{2}$" × pinfacer		
		dimension, turning jig	Holder		
	1	over for 2nd side.			
	5	Pinface boss about $\frac{1}{2}$" c. hole	$1\frac{1}{16}$" × pinfacer		
			Holder		
	5	Pinface boss about $\frac{1}{4}$" w. hole	$3\frac{1}{16}$" × pinfacer		
F.S.C. × 2	4		Holder		
	5	C'sink both tapping holes	90° C'sink.		
	2	Transfer fixture to next	Holder.		
		spindle.			
change × 4	20		3rd Spindle		
			Quick change chuck.		
$32 \times \frac{1}{4} + 2$	10	Tap $\frac{1}{4}$" w. hole	Tap.		
change	6		Holder.		
$32 \times \frac{3}{8} + 2$	16	Tap $\frac{1}{2}$" c. hole	Tap.		
			Holder.		
	2	Transfer fixture back	Screw plug gauge		
F.F.T.	151	to 2nd spindle.			
20% F.at	30				
	181				
25% F.V.	45				
	226				

FIG. 48. MASTER PROCESS LAYOUT. SHEET 3

PROCESS LAYOUT.

MAT'L.

DATE. 5/11/32

TITLE: Anchor Bracket

PART Nº 971

SHEET Nº 4

Nº OF SHEETS. 4

	OPERATION.	PLANT.	PLANT Nºs	OP. Nº LAB. GR. P.W.T.
	Set up M/C	Hor. Milling M/C. Fixture to locate similarly to that in op. 2 but arch gosh in mandrel to clear cutter. Clamp near gosh.	1049 71372	106 C 37·5
55 + 8 = 63 + 16 = 79 $\frac{1 \times 60}{2}$ 20 + 30 + 5 = 55 Return	Load. Mill 1/8" gosh 15/16" deep.	1/8" saw, 4" dia. Arbor. Spacing collars.		6 C 1·3
	Prepare.	Bench. Vice.		107 B 15·0
	Hold in vice. Remove burrs and sharp edges to suit inspection.	Files 1¾" × 20 T.P.I. hand tap. Wrench		7 B 2·5

Viewer

Send to C Assembling Shop.

For subsequent operations see MN Assembly layout 982.

The machines used may be those whose numbers are stated or similar ones.

FIG. 49. MASTER PROCESS LAYOUT. SHEET 4

Layouts for assembling operations may be made similarly to those in Fig. 46. It is desirable to specify all the parts (not forgetting tools and appliances) used, thus—

Assemble and adjust to inspector's requirements—

1. Bracket . . .	Part No. 243/1
2. Straps . . .	„ 244/2
4. Screws . . .	„ S. 167
4. S. washers . . .	„ S. 349
etc.	

This information will appear in the Operation column in the layout sheet.

The next business in making an estimate is to ascertain the value of the rough component as it is supplied to the machine shop. The bulk of raw material is bought by weight, hence, knowing the usual price charged per pound or ton, one can ascertain the value quickly as soon as the weight is known. There are plenty of inexpensive books on mensuration obtainable, and most of the engineers' pocket books contain all the formulæ which are likely to be needed for weight calculations, so they will not be given here. The easiest and best plan, of course, is to weigh the rough components when possible. When the weight must be found by calculation approximations should be largely used; a certain amount of intelligent guessing is justifiable for some of the minor details when the bulk of the weight in the component has been found.

TABLE XL

WEIGHT OF MATERIALS—LB. PER CUBIC INCH

Material	Average Value	Approximate Value
Aluminium . . .	0·095	0·1
Brass (cast) . . .	0·29	0·3
„ (sheet) . . .	0·31	⅓
Bronze	0·31	⅓
Copper	0·32	⅓
Ebonite	0·05	1/20
Fibre (vulcanized) . .	0·46	½
Iron (wrought) . .	0·28	0·3
„ (cast) . . .	0·26	0·3
Mica	0·11	1/9
Steel	0·28	0·3

The approximate value may safely be used for castings, forgings, and small articles.

A point to remember with all castings and forgings is that the actual volume and weight will be greater than expected if the drawing dimensions form the basis of the calculations and the ordinary figures of weight per cubic inch or foot are used. The reason is that drawings give, in practice, minimum sizes. The rough components made to those drawings will be thicker and heavier. Exceptions are few. On account of this fact it is wise to use weight factors which are larger than those usually given in tables and they can be chosen to simplify the arithmetic. This practice is altogether easier and quite as accurate as guessing how much larger than the intended sizes the rough component will actually be. It is much easier, for instance, to multiply by 0·3 than by 0·28 and definitely more satisfactory if the drawing sizes are used uncorrected.

Table XL gives the weight factors for a few common materials. The left hand column shows the weights per cubic inch usually listed and the right hand column the equivalent which it is justifiable to use for estimating.

TABLE XLI

MATERIAL PRICES PER LB.

	s.	*d.*
Aluminium sheet	1	1
„ die castings	1	1½
„ Bronze die castings	1	–
Brass sheet		8
„ castings		8
„ rod (standard section)		5
Iron castings		2 (average)
„ malleable castings		5
Fibre sheet	1	6
M. steel sheets		1½
„ „ (deep drawing)		2
„ bars (bright)		1¼
„ stampings		4 (average)
„ tube		4½ „
Solder		8½

The next list, Table XLI, indicates prices for some common materials. Such figures can only be temporarily

serviceable in a very limited way. Moreover very much depends on the quantities bought and the keenness of the buyers. Another factor is whether the charge for delivering at the works is included in the price or not. Small firms who buy small quantities often pay nearly twice as much for their supplies as do large buyers. Current prices may be studied in the trade journals. Of course these do not apply to special requirements, for which in any case the charge will be much higher. If tenders are obtained it will be found that the figures vary widely, especially when machined or partially machined components are bought. The variations may be due to wrong estimates, to different interpretations of the customer's requirements or to facilities which a firm may have or lack as compared with others. The two last are by far the most important.

The cost of patterns, casting and stamping dies, gauges and tools is not included in overhead charges when they have to be made specially for one contract. If only a few sets of components are required the expense of each set may be very much increased by the cost of the patterns, however economically they are made. Special tools will be restricted, too, to the essentials necessary for securing accuracy or interchangeability. It is easy, however, to settle what is appropriate when quantities are either small or large; the difficulty arises for intermediate numbers and the only way to determine the matter satisfactorily then is as explained in the next chapter. For the immediate purpose it is only necessary to state that the cost of special patterns and tools must be charged against the product.

Something towards obtaining a reasonably close estimate of the cost of patterns may be done by referring to past records of similar work.

If possible this should be supplemented by calling in the aid of the pattern shop rate fixer or foreman. Skilled advice is desirable because the quantity of castings required off a pattern may affect the way it will be made;

and in any case these specialists will be able to save a great deal of the estimator's time, replace guessing by practical certainty, and, later on, if the contract is secured, take decisive measures to prevent the estimated costs from being exceeded.

Similar remarks apply to dies and all other tools. Toolroom foremen, for instance, generally have a fair idea of the cost of making tools. It is part of their job. The old-fashioned machine shop foremen, too, often could estimate closely by looking over a drawing or sample. But few modern machine-shop foremen can tackle the whole course of manufacture of even a single component. They are mostly specialists, and rate fixers are, in general, far better guides if advice is sought on production times.

Oncost or overhead charges may be added to the prime cost of each component, or, more conveniently for quick estimating, to the set of components in each assembled unit. For definitions of oncosts, etc., reference should be made to Chapter XI.

Some data for process costs were given in Chapter IX. Process costs or charges are production costs which cannot conveniently be treated in the ordinary way because of difficulty in allocating a time for each component separately or because the labour-time basis is unsuitable, being perhaps trifling as a charge compared with other expenses which may not vary directly with it. It will be found simplest to include overhead charges in the process charge. Some estimators include only labour and indirect materials or some other combination of partial costs. It is difficult to understand why.

The cost of each unit will be the sum of the costs of all the components, plus the assembly cost and all the bolts, washers, etc., used in that process. Similarly the cost of the whole machine or apparatus will be found by adding together the costs of the units and assembling them.

Some of the units may have already been painted or

enamelled or the whole of that process may follow testing. Painting is sometimes added on as an overhead charge, but it is better to reckon it as a part of direct production in the form of a process cost.

Testing and adjusting also are often included in overheads, probably because they are associated with inspection, which generally is an overhead charge. It is better if possible to rank them with production; many firms on intensive production pay for them and any adjustments or rectification found necessary on a piece-work basis. The argument against it is that the work may be scamped, but this is not found to be the case when supervision is good and each man's work is booked to him carefully.

Testing procedure can be planned on exactly the same lines as other forms of production, and a layout sheet made to match the test report sheet.

Packing may be treated in the same way. The whole of the materials used can be specified and times allotted to the various operations similarly to the method shown for assembling.

The cost of delivering the completed work to its destination may also have to be added. This cost should be obtained as required from those who will carry out the work.

In some classes of work there will be erection and testing after delivery and possibly service afterwards. No rules can be given. When possible the cost should be charged direct to the job but sometimes it has to be included in the oncost or surcharge.

Patent royalties should be charged direct, but frequently the estimator has no knowledge of these and they are added with certain other charges to his estimate of the work or factory cost, as shown in the next chapter.

Rough estimates are usually summarized as shown below, the cost of the various items having been previously ascertained, as already indicated.

Part	Part No.	No. Off.	Material	Mins. Lab.	Process Charge
			£ s. d.		s. d.
Base	1458	1	4 6½	640	—
Pedestal	3142	2	2 8	210	—
Cap	3143	2	1 6	60	—
Cover	2301	1	3 –	320	1 6
Total. . .			£8 6 4	10,740	7 9½

10,740 mins. at 1s. 6d. per hour = £13 8s. 6d.

	£	s.	d.
Special tools .	79	10	–
Patterns .	34	10	–
	£114	–	– for 50 sets = £2 5s. 7d. per set.

Summary—

	£	s.	d.
Materials.	8	6	4
Labour	13	8	6
Overhead at 150%	20	2	9
Process charge		7	9½
Tools and patterns	2	5	7
Estimated cost per set . . .	£44	10	11½

This cost includes no allowance for contingencies, packing or despatch.

This form of estimate is the most common. It can be prepared rapidly, especially when the labour calculations are made as on page 219. The oncost or overhead charge of 150% is a common average figure. It must include machine setting up charges unless these are reckoned elsewhere. The matter of oncost rating is more thoroughly studied in the next chapter, so it is unnecessary to consider it further here.

There are books dealing entirely with the preparation of estimates for tendering and to them those who require more detailed information on the subject are referred. Here the bare principles have been indicated for what may be called workshop estimates as prepared by foremen or production engineers, and for their purpose no more is needed as a rule. Should it be, the aid of a cost accountant is desirable, or a professional estimator.

CHAPTER XI

WORKS ECONOMICS

It is necessary to commence this study by defining the terms used. The variations in meanings which different people give to the same words cause misunderstanding and confusion. Before the cost data of any works can be properly appraised by an outsider he must ascertain how the various terms are used, what they include, and what they omit.

For the present purpose the total cost of a product is to be considered as being made up of expenditure under four heads:

Materials
Labour
Oncost or Overhead Charges
Surcharge.

The word "materials," unqualified, means *direct materials*; that is, those which are either wholly or fractionally present in the finished product. *Indirect materials* are used during the processes of manufacture but do not appear in the finished product. Examples are: polishing materials, fuel, anti-hardening paint, lubricating and cleansing oils.

The cost of these is generally included in the overheads because it is not easy to allocate a fair share to specific units by other means, nor is it often necessary to make the attempt.

Labour, unqualified, means the labour which is *directly* engaged in production, such as turning, grinding, or fitting. Indirect labour is employed to assist the direct producers and is necessary for them to work efficiently. The division between direct and indirect labour is hazy. It is more a matter of book-keeping than anything else. If a labourer is permanently working with a gang of erectors his time

can be definitely allocated to the job they are doing, and he is a direct producer with them. But a labourer who helps several mechanics in turn, perhaps doing a little sweeping between times, would generally be ranked as indirect because it would make his time records too complicated (and they would seldom be accurate) for him to book his time against the various jobs he helped along or did during a day. Indirect labour is conveniently treated as an oncost.

That the distinction between direct and indirect labour is merely one of book-keeping should be firmly grasped because too often it is assumed that the direct variety is more necessary, or more important, than the other. One may as well assert that a centre forward is more important than a goal-keeper.

Oncost and surcharge are frequently taken as one and given other names, such as burden, establishment or overhead charges, or indirect expense. Here they will be separated for reasons which will presently be seen, overheads or oncost being limited to mean those indirect expenses which appertain to the manufactory or works and are largely, though rarely entirely, under the control of the works directors.

Surcharge includes the higher administrative expenses and other charges which cannot fairly rank in the overheads (such as some legal and other professional services, selling expense and service after sales) because not under works control.

Overheads may be divided into *fixed* and *running charges*. Fixed charges are those which vary little whether the works be busy or slack, such as rent, rates, depreciation, salaries of the higher officials, and so on. Running charges vary, though not proportionately, with the amount of works activity. Examples are wages of inspectors, general labourers and minor members of the staff, power supply, maintenance of small tools, etc. The surcharge may be similarly divided, but variations in general administration

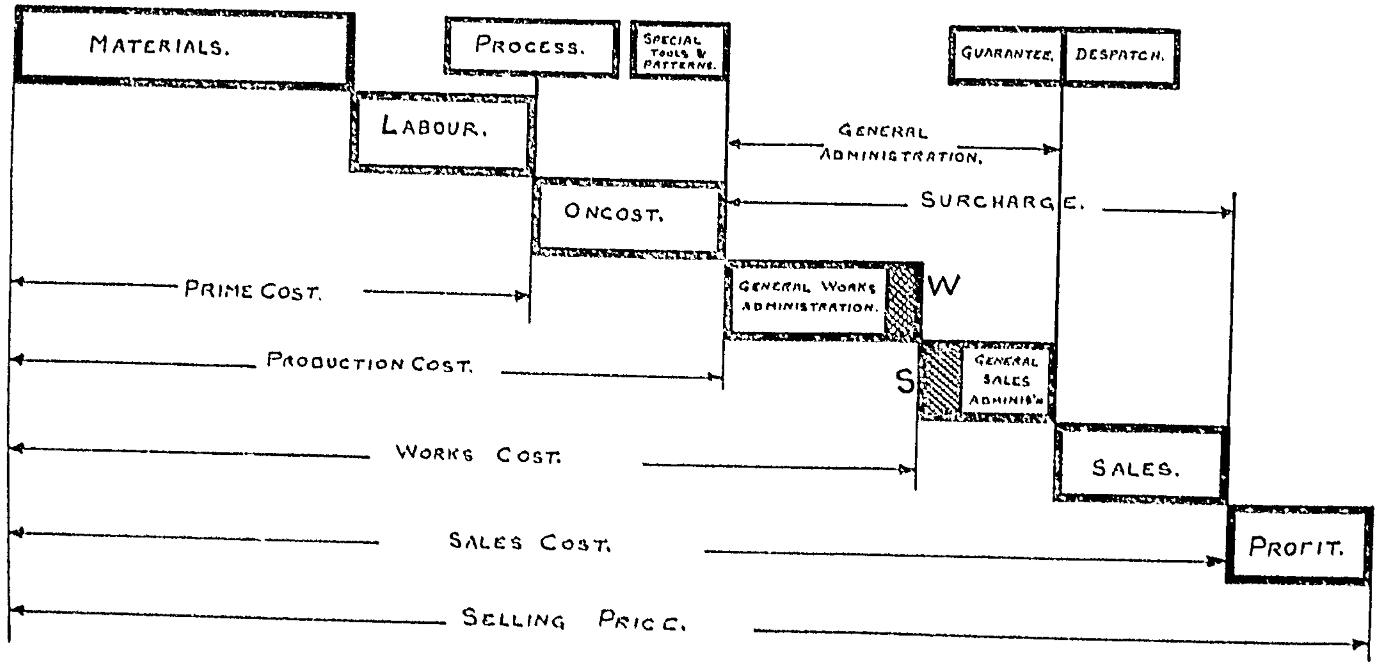


FIG. 50. COST BUILDING

or selling expenses rarely synchronize with changes in the amount of works production.

Material cost plus Labour cost	= Prime cost.
Prime cost plus Oncost or Overheads	= Production cost.
Production cost plus Surcharge	= Sales cost.
Sales cost plus Profit	= Selling price.

These relations are shown graphically in Fig. 50.

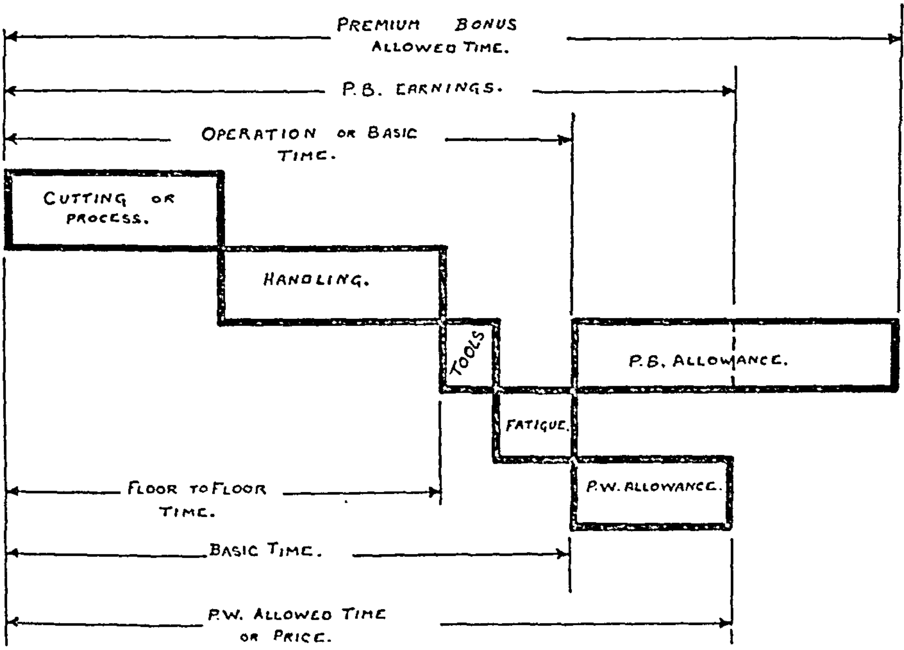


FIG. 51. LABOUR COST

It also indicates other relations which will be referred to later and is, in some sense, a definition of them. In a similar way Fig. 51 shows how labour cost is built.

If an organization A have a Works W and a selling organization S under its general direction, but does nothing else, its expenditure can be divided into three parts—

(1) That which is directly on account of W.
(2) That which is directly on account of S.
(3) General expenditure to maintain itself.

It is obvious that all three are expenses which must be added ultimately to the sales cost of the product. One may consider A's activities on behalf of W and S as its production and its general expenditure as its overheads. The last amount must be distributed between W and S as seems fitting. It is indicated in Fig. 50 by the shaded areas at W and S.

The works could not exist and run without A, consequently the *works cost* is found by adding to the production cost the amount of item 1 as indicated diagramatically. Similarly the addition of the whole surcharge to the production cost results in the *sales cost*. If the product were sold at sales cost there would be neither profit nor loss.

In practice A is usually bound up so intimately with W and S that the functional distinction is not plain at first sight. Yet it always exists, even in a one-man concern, and if that is remembered the business of overhead and surcharge distribution becomes comparatively easy.

Of course the steps in the diagram are not to scale; they merely show roughly the order in which the various items may conveniently be considered. Usually it is convenient to assess the surcharge as a percentage of the production costs.

This is probably as good a way as any since the more expensive the product, the more it can reasonably be expected to carry of the general administration and sales cost. Certainly it is wrong to vary the surcharge with the wages of direct labour alone. The percentage used need not be invariable for all products; it may be adjusted at the discretion of the general management to suit differing circumstances. Neither overhead nor surcharge as used for estimates can be allowed frequently to vary. What may be termed normal rates should be used; the current rates fluctuate with the state of trade and in the directions which are not helpful towards stability.

As far as possible each item comprised in overhead

charges should be shared by its related production units in proportion to the benefit they obtain by using it; and the sum total of their shares should, as nearly as possible, equal the total cost of that item; while the total of all the shares of the several times should equal the total overhead. This is an ideal which cannot, in engineering works, be perfectly attained because the conditions change too rapidly and in too complex a manner for accountancy to keep pace.

Many firms add a percentage to the cost of materials to cover the cost of handling and storing them and to allow for wastage. The amount is usually 5% or 10%. This is quite reasonable but seems unnecessary. The material is stored for the benefit of production and the production overhead may well include the expense. Wastage is on a different footing. There is little waste on finished components such as ball-races, instruments, and units which are bought in ready for assembling. On items such as bolts and washers there is sure to be some loss. The waste in cutting up bars and sheets is always considerable. By careful planning it can be minimized and the best way to control it is by specifying on the layouts the gross amounts which will be needed to make a stated quantity of finished components, not allowing for faults in materials or workmanship. The average expense of rectifying or replacing defective parts may usually be reckoned as part of the overhead unless there are special circumstances.

Sometimes overhead charges are reckoned as a percentage of the prime cost, generally somewhere between 50% and 100% of that. Where the range of production is extremely narrow and seldom changes this method averages out fairly well. But it fails to give true component costs and will fail if the value of the raw materials alter, or a different kind of production is undertaken, unless a suitable adjustment is made to the percentage.

The commonest way of estimating overhead is as a

percentage of the total direct labour cost. It is often used by estimators to obtain quick results.

It does not give a true component cost or a true production cost when varied manufactures flow through together. The method of obtaining the percentage is to take a suitable period and to compare the total direct wages with the oncost expenditure during that time.

A far better plan is to take departments instead of a whole works and to assign to each its own percentage of oncost in just the same way as that recommended for process costs.

But the worst feature of the percentage on labour method is that it distorts special cases. For instance, suppose the wages of direct labour for doing certain work amount to £100 and overheads are reckoned at 100%. Now suppose that by better planning and supervision but no other changes the wages cost for doing the same work is reduced to £80. What grounds are there for assuming that the overhead has also come down to £80! None! Eventually, at the time for the revision of the overhead charge, the new percentage will be found; but that will be too late for estimates and contracts made meanwhile. Again, if by shift working or overtime the men earn £120 for the same work there is no reason why overhead should also rise to £120. Often, in fact, by working overtime the overhead is reduced in proportion to wages to such an extent that the cost of production is not increased, although wages are enhanced.

The mistake occurs through believing that the overhead is a fixed charge in relation to wages, whereas it is a charge for services or facilities which may be largely independent of the wages expense. If production is increased but not changed in style, the total wages of direct labour will rise and so will the total overhead, though not on the same scale: as a rule the *amount of the overhead charges per unit of production will fall when* the volume of production grows.

Time happens to be a (rough) measure of many of the

items which make up overhead. Wages also are based on time; but since they vary considerably with the class of labour and other conditions it is not generally true that overheads vary with wages. It is the *output, not the time*, which has to carry all overhead expenses.

For most purposes the best way of distributing overhead is on a time basis according to the process. This may be done by assigning an hourly rate to each machine or production station. The business is always approximate, a fact which the most meticulous care or the most elaborate system will not alter. Hence it is sufficient to divide the bulk of the machines (or production stations) into a few groups, assigning to each group its proper hourly overhead rate, those exceptional processes or machines which require it being given special rates. The work of distributing overhead falls upon the cost accountants, but it is desirable for production engineers to have a clear idea of the principles involved. Records made over a period enable an accountant to assign to a given machine (or group of machines) an overhead rate depending on—

(1) The floor space it occupies (because this is a measure of its share of rent, rates, general lighting and heating, etc.).
(2) Its book value (because that governs depreciation and insurance).
(3) The amount of supervision, clerical work, store keeping, inspection and other indirect labour which is necessary for the machine to function properly in conjunction with the rest of the works. As a rule the due amount cannot be entirely calculated but has to be intelligently guessed after considering all the circumstances.
(4) Its consumption of power, special lighting, tools, oil, and other indirect materials, crane service, etc.
(5) The cost of maintaining it in good running order.
(6) The amount of idle time and scrap work for which it can fairly be charged.

(7) Its estimated share of the general office and miscellaneous expenses.

The above list is by no means exhaustive: it merely indicates some of the principal items which make up overheads and the manner of allocating them.

A typical list of overhead hourly rates may be—

Per hour s.	d.	
1	6	Assembling and light fitting
2	–	Erecting, sensitive drilling, and other small machines
2	6	Small lathes, column and light radial drilling machines; small milling machines
3	–	Polishing machines
4	–	Small power presses, larger lathes, etc.; small autos.
5	–	Medium power presses, medium autos.
7	6	Heavy power presses, drop stamps, large boring machines, heavy lathes, and milling machines
15	–	Special precision machines, heavy double action presses

In practice rates vary widely, partly owing to different conditions and partly because some accountants treat certain expenses as a direct charge which others rank as an overhead. Paint, for instance, can be reckoned as an overhead or be charged as a direct material in the process cost. The production engineer will be advised by the cost accountant as to the method of charging, and prepare his estimates accordingly. The several machines which are ranked to bear, say, 3/- an hour overhead, may not all strictly be carrying their fair share. Some should, perhaps, theoretically take 2/10 and others 3/2 an hour. A certain amount of averaging simplifies matters and will not result in sensible error if carefully done.

As an instance of the different effects of estimating by the percentage and by the hourly process rate the llowing example is instructive. Material costs are gnored.

A mechanism is made in two sizes. The smaller takes 100 hours to make and the larger 140 hours on machines generally heavier than are required for the first. The average labour rate per hour is 1/- and the overhead is reckoned at 200% of wages.

	£	s.	d.
Small mechanism—			
Labour: 100 hr. at 1s.	5	–	–
Overhead at 200%	10	–	–
Large mechanism—			
Labour: 140 hr. at 1s.	7	–	–
Overhead at 200%	14	–	–

But when the overhead is calculated by the hourly rates suitable for the processes used the results are as follows—

Small mechanism—	£	s.	d.
26 hr. at 1s.	1	6	–
20 hr. at 1s. 6d.	1	10	–
36 hr. at 2s.	3	12	–
12 hr. at 2s. 6d.	1	10	–
6 hr. at 3s.		18	–
Total	£8	16	–

Large mechanism—	£	s.	d.
20 hr. at 1s.	1	–	–
14 hr. at 1s. 6d.	1	1	–
36 hr. at 2s.	3	12	–
40 hr. at 2s. 6d.	5	–	–
20 hr. at 3s.	3	–	–
10 hr. at 3s. 6d.	1	15	–
Total	£15	8	–

It follows that if the two mechanisms are made in approximately equal numbers the 200% rate will be nearly right, since it amounts to £24 for a pair consisting of one large and one small one, while by the hourly rating the overhead for the same pair equals £24 4s. 0d.

The likely effect of quoting for supplying these mechanisms on the 200% basis would be to lose orders for the smaller size since the price is inflated, and to lose money on the whole.

For instance, an order for 20 small and 80 large mechanisms would carry an overhead of £1,320 on the 200% basis. But the hourly rating gives an overhead of £1,408. Increasing the overhead from 200% to 214% would further penalize the small mechanisms and so, probably, not have the desired financial effect.

Evidently the proper distribution of overhead charges is immensely important when competition brings prices low. The fancy that overhead is related to wages in a fixed ratio, such as the 200% in the above example, is responsible for many wage cuts. If it were a fact a cut in wage rates of 5% would, in the example, bring about a corresponding reduction in overheads and the business would be as prosperous as expected. But that way of reducing cost is comparatively ineffective. There are two far better policies. One is to analyse all the circumstances and to plan and control more efficiently. The second is to estimate the sales possibilities, on the assumption that prices could be reduced if the turnover were increased, to cut prices (or give increased value) in anticipation and then force the sales to the level required to make the business sound. All of these three ways are in continual use. The safest and best is that which depends on analysis and planning, especially when it is supported by ingenious designing, and the application of the more vigorous sales policy. Although the production or estimating engineer may not be directly concerned with sales he can often, if he thoroughly understands the principles just outlined, influence quotations. By working closely with the cost accountant he can be sure of his facts; and the two together may sometimes be successful in partially reshaping a firm's price policy.

The surcharge is seldom distinguished definitely from oncost in writings on the subject. Most engineering firms, however, do make a distinction, in practice, although they may not use the above terms. The definition of factory or works costs as indicated in Fig. 50 makes that include production cost and part of what is here called surcharge. It is sometimes convenient for this part of the surcharge to rank as an overhead, especially when its amount is comparatively small. In that case production cost and works cost are synonymous.

If desired, for simplification, a machine or process rate

may include both wages and overhead. For instance 1/6 an hour wages and 2/6 an hour overhead are equivalent to a 4/- an hour rate for a process. In general the combination of the two rates into one is quite satisfactory for estimating because the estimator and the prospective customer are interested only in the total, not how they are compiled. For works control, on the other hand, it is essential to know the details.

There are several other items to be considered in making an estimate. First there is *Process Cost* as shown above the labour step in the diagram. Some include only indirect materials in process costs. It is better to have them include direct and indirect materials, labour, and overhead but no surcharge. For work of a special character there are generally patterns and tools to make, the cost of which will be extra. An unusual performance guarantee may be required by the prospective customer and this will require consideration. These further items are indicated in Fig. 50.

The cost of packing and delivery may include such items as special protection against sea air, customs duties, and the rate of exchange. As a rule the estimating engineer has to show special factors separately and is not responsible for the total amount of surcharge included in the sales cost. Indeed, he frequently goes no further than reckoning the production cost (or it may be works cost), perhaps adding packing charges to that, the remaining charges being added by the general or the sales management. The amount paid in "royalties" or "licences to manufacture" forms a part of the surcharge.

The matter of tools deserves further consideration. The overhead provides for the whole of the ordinary tool expense but not for anything special. Hence if new jigs and tools are required for products which are not standard the extra cost must be allocated to those products. Sometimes further orders may be expected to follow that for which the tools are to be made. Then, either the tool

cost can be spread over a larger number than quoted for in the first place, or subsequent orders can be executed for a lower price. The tool cost may be the price of the tools bought from a firm of toolmakers, it may be the production cost or the prime cost when made in the works toolroom. It is safest to base it on the bought out price. Occasionally one hears the remark that the toolroom is an overhead, that there cannot be an overhead on an overhead and therefore there cannot be an overhead on tool making. The fallacy of this reasoning should be apparent from the definition of what an overhead really is. There are sound reasons why the toolroom overheads are comparatively low. But entering upon the manufacture of home-made machines, for instance, completely changes the conditions if done on a large scale. It is usually a fallacy to believe that one saves by it although the price "home-made" may seem low on account of fictitious overheads.

There is another point to consider in connexion with special tools and the delivery date of the product. Simple, small jigs and tools can be completed in a week or two if they are not too numerous. Large tools may take two or three months or more to finish and it is quite possible that a good deal of the production they are intended for will have to be done without them. The questions must be asked, then, will it be worth while to order them? Will the saving on the small amount of production remaining when they become available for use pay for them?

Again, when estimating the saving, what items should be reckoned? There will be the obvious economy in labour, not forgetting that assembling or erection is likely to be eased when supplied with a more accurate product. Part of the overhead associated with that labour will also be saved—not all, for comparatively inefficient manufacture swells labour above normal and dilutes overhead because there are more production hours over which to distribute it.

The business of comparing the costs is best done by tabulating thus—

Cost without Tools		*Cost with Tools*
Labour = A		Labour = C
Overhead = B		Overhead = D
	Price of Tools = E	

Then if A + B is less than C + D + E it obviously will not pay to have the tools. This method is rather too complex for many occasions; the overhead value D will have to be guessed if it is not laboriously calculated, and B will, as stated, be less than the normal oncost if that includes tools; the state of trade may make it desirable to employ the works toolroom, to retain good men through a slack period. In these circumstances it is advisable to leave out overhead B and D and to substitute for E the estimated prime cost of the tools. However the comparison is made, it is only rough. It should be regarded as a safeguard against absurd expenditure rather than a scientific balance.

Incidentally, the above-mentioned dilution of overheads illustrates the fallacy of the assertion that a high (or low) overhead is a measure of managerial efficiency. Usually, low production efficiency per man-hour is associated with low rating but not necessarily; and high overheads are not a sign of efficient production. Although intensive manufacture often carries high overheads as an hourly rate the burden is comparatively low per unit volume of production.

Another point worth mentioning is that the economic values of different tools may be compared on the lines indicated in the last paragraph. For example, the performance of different brands of cutting tools may be compared.

	Brand A	*Brand B*
Cost of tool	25s.	2s. 8d.
Life of tool in components . . .	1,000	400
Tool cost per component . . .	0·30d.	0·08d.
Labour cost per component . . .	1·2d.	1·4d.
Tool + labour per component . .	1·5d.	1·48d.

If the overheads are known for the two cases they can be taken into account. It is not at all certain that they will vary with labour cost or time—almost certainly not. The usual rating will fail. And it is quite true that quicker cutting with more expensive tools may be less economical than ordinary working.

DATE: ______ **COST LAYOUT.** PART No. 1071

TITLE: ______

FORM. Stamping WEIGHT. 48 lbs. PRICE. 3d per lb. = 12/-

OP. No.	PROCESS or OP.	M/C.	PLANT No.	HOURLY RATE.	LABOUR RATE	ACTUAL TIME.	LABOUR COST. (25% P.W.)	ONCOST.
1	Turn large end	Capstan	109	48d.	60/-	12·0	3·82	9·60
2	" small end	"	121	48	60/-	15·0	4·79	12·00
3	" neck	C. Lathe	84	36	60/-	6·0	1·92	3·60
4	Mill flange	H. Mill	57	36	50/-	5·2	1·37	3·12
5	Grind flange	Ext Grind	130	48	50/-	4·6	1·22	3·68
6	Grind bore	Int. "	142	36	45/-	3·0	0·72	1·80
7	Drill	Sens. Drill	63	24	30/-	7·5	1·20	3·00
							15·04	36·80
							36·80	
							51·84	
						Materials	144·00	
						Total	195·84	d.

FIG. 52. COST LAYOUT

A Cost Layout sheet is shown in Fig. 52. This is self-explanatory. It will be noted that it employs hourly ·+ - for the operation oncosts. By summarizing these vı a more reliable estimate is obtained than is ıle when an average percentage is used for the head or oncost but the time and expense involved is ıst this method being universally employed or for uick estimates.

Overheads are based on actual working times, not piecework time allowances or prices, as a rule. It is important

to avoid confusion between these bases. Since piece-work or equivalent systems are in general use and available data often relates to piece-work time allowances, it sometimes simplifies the arithmetic to use overhead rates which are adjusted to time allowances. For example a rate of 2/- an hour actual time will be 2/- ÷ 1¼ if calculated on time allowances which permit time and a quarter to be earned on the average. The "cost of living" bonus needs similar adjustment.

If the production cost of a component is compared with the price quoted by an outside contractor, it is sometimes found that the latter is lower. Does it then pay to buy the finished component? It is not necessary to consider the surcharge because that will be the same in both cases. This alone is a good reason for differentiating between surcharge and overhead charges.

Suppose the production cost of a component is 2/3 and the best outside quotation is 2/-; would acceptance of the latter save 3d. each?

Let the production cost be made up as follows—

		s.	*d.*
Material		1	–
Labour			8
Overhead	Running charges, 4d. Fixed charges, 3d.		7
		2	3

By buying outside the labour is saved; supervision, clerical work, inspection, etc., are practically unchanged, the running charges are reduced by, perhaps, 50%; that is only 2d. Hence the real cost of the bought out component becomes—

	s.	*d.*
Material	2	–
Overhead		5
	2	5

At first sight it appears that here an overhead has been added to the material expense contrary to what was

recommended earlier. But this charge has to be borne by the component. If it be not reckoned as shown above then all the overhead ratings on other production must be raised to make up the deficit—obviously neither a practical nor a useful procedure since the above method is equivalent. Of course this supposes the overhead rating to be correctly assessed in the first instance.

Many do not believe in placing work outside if the quoted price is above their own prime cost. This is too drastic. Running charges often amount to about half the overhead and generally an outside quotation may safely be accepted as economical when the price is not higher than the production cost less 70% of the overhead. As suggested in the example, it is rare for the whole of the running costs to be saved—it may be only power and tool maintenance.

The reasons why one firm should be able to make its selling price lower than another's production cost are always worth investigation and consideration. Of course, the sub-contractor will not have designs and drawings to make. He may have superior facilities or be a bad estimator. He is seldom credited with being a better manager.

The effect of buying many instead of a few components from outside can be gauged from the last example. By shutting down the whole or a large part of the machine shop the distribution of overheads is entirely changed: the remaining productive departments will have to be rated anew at higher figures unless the disused works and plant can be sold. When this is taken into account together [illegible]ith the many disadvantages which dependence on out-[illegible] always brings it will rarely be found economical to [illegible] from outside contractors more than is strictly [illegible]ssary.

[illegible]here are numerous standardized components which [illegible]re manufactured in large quantities by specialists. Ordinary firms cannot successfully make ball races for instance. Nor does it pay firms, as a rule, to make their

own bolts and screws. But when it is a matter of special components outsiders are handicapped. Drawings and specifications do not invariably tell the whole story. The men in one's own works know what is wanted, how to lean to the small side of that dimension and to the large side of another, the class of finish which is necessary, whether this feature must be rightly placed in relation with X or with Y (granted that some error is unavoidable), and generally how to interpret the drawings and use the gauges to the best advantage. To obtain adequate supplies of castings, sheets and bars is comparatively easy; to co-ordinate satisfactorily the supplies of finished components from sub-contractors is frequently impossible.

With good planning and regulation of supplies large stocks of idle components never accumulate (unless designedly, for seasonal trade). There is enough, but never much more than enough, to permit production to flow at the desired rate smoothly. Idle stocks represent idle money, perhaps borrowed money. The interest on that idle capital may make the difference between profit and loss on a contract. The money locked up in stores or in components lying around the shops may prevent a firm from buying profitable plant. A consideration of these facts again leads to the conclusion that a firm should produce all that it reasonably can in its own works, maintaining substantial stocks of raw materials but only sufficient machined components for immediate use.

Improvement in the quality of machine work has a value which is real, yet may not be easy to express in figures. New machines are often bought because existing plant will not give the desired accuracy or finish. It may be decided that they shall be obtained without it being possible to prove that their installation will save enough money ever to pay for them, although everyone concerned is convinced that it will. But most machinery is bought to earn a profit which can be estimated beforehand.

When a new machine is installed the effect on running expenses is often obscure; labour and fixed charges are easy to estimate. There are three principal cases to consider as regards that part of the oncost known as running charges—

(1) If the machine replaces another and saves labour, but the general output is not increased, the running charges will generally remain unaltered; that is, they will be just about the same for the new as for the old machine per unit of production, though not, perhaps, per hour. The power consumed will vary with the amount of metal removed or work done; whether it be done slowly or quickly scarcely affects the result. The foreman's salary cannot be reduced because fewer man-hours are worked: inspection and transport will amount to as much as before. A little consideration will show that nothing of any consequence has been changed in the other incidentals either.

(2) If the machine replaces another which has been a "bottle neck" the effect is very different. To obviate the "bottle neck" effect the old machine will have been worked longer than normal hours. And not only the machine operator but possibly an electrician will have attended during some of the extra time. There have been overtime pay and, probably, other expenses which would otherwise not have been necessary, expenses such as those incurred by running a large power unit with a light load, or for general shop lighting for the convenience of one small area. These are running expenses which the new machine, by dealing with the required output during normal working hours, will save. It will directly consume about the same total amount of power as the old machine used directly, and that must be charged against it, but

its other running expenses will be those borne by the old machine running normal time, unless extra labour is required for transport or some other incidental service to an extent which is worth considering.

(3) If a high duty machine is installed to replace a low duty machine as part of a quickly effective policy of converting a whole section of plant, the running charge of the new machine may be assessed at its eventual rate, that is the rate which will be fair when the conversion is completed. If the new section has the same capacity as the old it will probably be much smaller in extent and it may save running expenses in several ways. On the other hand, it may save in labour only: one cannot be sure until all the circumstances are known. The point is that there is no golden rule: because a machine is modern and high powered it does not necessarily follow that it is better economically, even as regards the limited share of overheads known as running charges, than older machines of low power. Each case must be studied, the effect on the principal variables must be judged. It is the quantity of production in a month which counts, not so much whether a month's supply can be done in two weeks or four.

As a rule the selected new machine will be that which appears to be the best profit earner. But the figures in the quotations from the suppliers will not be the only guide to that. Guaranteed production rates are seldom taken quite seriously; or are not enforced because the guarantees only apply under conditions which may not be realizable in workshop practice. After the sale is completed some firms will be unsparing of trouble and expense to satisfy their customers; others will care less. Service of this kind has to be paid for. The price of it cannot

very well be set out as an item in a quotation; yet it is known to be included and will be assessed by the buyer though not definitely in pounds sterling.

The first arithmetical example is chosen to illustrate bare principles without refinements or complexities.

A machine which originally cost £200 has now a book value of £60; will it pay to replace it by a new machine which can produce faster but costs £300?

For brevity call the first machine A and the second B. A produces 100 components a week, all that are required, and works 50 full 47 hours weeks in a year. The operator earns £3 18s. 0d. a week. B is guaranteed to produce the components at the rate of 14 minutes each, floor to floor time.

Since only 100 components are required per week B cannot produce the whole of the time unless other work can be found for it. Let it be supposed, for simplicity, that this is impossible. The guarantee does not mean that a finished component will come from the machine once every 14 minutes of the working time. All that it implies is that, starting with everything in "apple pie" order, one component can be finished in 14 minutes. Perhaps the rate could be maintained over an hour, perhaps not. The conditions must be examined and due allowances made for fatigue, tools, and other contingencies as described elsewhere in the book. It is found, perhaps, that 30% must be added, bringing the basic time to 18·2 minutes.

$$100 \times 18.2 = 1820 \text{ minutes per week.}$$

A 47 hours week contains 2,820 minutes. If the operator is to earn at the same rate per hour as while he worked A his weekly earnings on B must be

$$\frac{1820}{2820} \times 78/- = 50/- \text{ (approx.)}$$

If the machines are for cutting metal they will both remove the same weight per week and will consequently

(probably) consume nearly the same quantity of power though at different hourly rates. Tool maintenance, inspection, the consumption of cutting fluids—all the running charges will be just about the same for both machines. Fixed charges will be unaltered except for the one item of depreciation. Hence the overhead need not be considered as a whole, but depreciation must be reckoned. (Note: if other work were found for B the change would be to its advantage because the overhead would then be distributed over a greater output.)

The majority of accountants reckon depreciation on diminishing values. A being worth £60 would have a depreciation allowance of £6 if the rate were 10%. On the other hand some advocate a flat depreciation allowance based on the original value. A's first cost being £200 it would be depreciated £20 a year (on the 10% rate). One great objection to the more orthodox method is that it produces, in the case of old machines, extremely small depreciation figures (compare the £6 with £20 in the case of A). The effect of these small figures is to enhance the apparent commercial efficiency of old plant and delay its replacement.

Using the second method of depreciating, the weekly depreciation on A equals 8/- and on B equals 12/-. Hence for producing 100 components Labour + Depreciation = £4 6s. od. for A; and £3 2s. od. for B. Therefore replacing A by B will save £1 4s. od. per week.

Many believe that interest on capital should also be included similarly to the depreciation. Thus, since B will cost £300 and A will be sold (it is hoped) for £60, the extra capital required is £240. At 5% the interest on that is £12 per annum to set against B. Of course the extra capital may have to be borrowed but the expense should be set against the firm, not the machine. Still, the amount of extra capital to be invested in the machine must be considered in relation to the machine's earnings. B saves 24/- a week, or £60 a year. As it happens, that is a return

of 25% on the extra capital, which is adequate. But if it had been only £10 a year it might justifiably be held that to replace A by B would not, in the circumstances, be expedient.

Another way of deciding whether to purchase B is to consider what is termed the *Recovery Period.* By this method depreciation is not reckoned directly. The savings which the installation of B effects for a week (or a year), taking into account any change in the running charges, is divided into the capital expenditure. The quotient represents the period of time in which the saving equals the expenditure. The running charges being the same for both machines, the weekly saving due to B amounts to £1 8s. 0d.

$$\frac{\text{£}240 \text{ 0s. 0d.}}{\text{£}1 \text{ 8s. 0d.}} = 171 \text{ weeks.}$$

Many would reject B because the recovery period is so long, being over three years. It is often held that one or at the most two years is all that can safely be allowed. This is an unsound belief. There can logically be no such rule. If there were, seven years would be more suitable as a limiting recovery period for standard machines than one or two years. It is far more satisfactory to forget about recovery periods and ascertain merely whether the machine is likely to earn a satisfactory profit or not.

Now suppose there were another machine like A but newer, worth, say, £180 by the books. Its recovery period would be

$$\frac{\text{£}(300 - 180)}{\text{£}1 \text{ 8s. 0d.}} = 86 \text{ weeks.}$$

In other words, the older and more worthless a machine the harder its replacement becomes by this recovery period theory, which is, therefore, absurd. Depreciation on diminishing values may give a book value nearer to the realizable second-hand value of a machine, but that

of little importance compared with having efficient lant which will earn substantial profits. The conserving .f capital in the form of decrepit plant is a plague which eventually destroys capital. Plant is bought for use, to earn a profit during its working life; its second-hand value is of little or no consequence unless its life is unexpectedly shortened. One should not conduct the business of production expecting and providing for early closure.

Machines which are not standard (and in this respect jigs and fixtures are similar) may have a short life and must be depreciated accordingly. For instance, if B were a special machine of no use to any other manufacturers and it was believed that a change in the design of the product would render it obsolete in one year, it must be depreciated by the whole £300 (less its value as scrap) in the first year. Obviously it would not pay to buy it in that case. It might be possible, if it had been installed, to adapt it to some other purpose by spending, say, £50 upon it. Then it would have a new life and the immediate depreciation would be the difference between its second-hand value and £350.

The next example is more complex. Two machines, A and B, will each yield 150 components in a 47 hours week for 50 weeks in a year. It is desired to raise the output to 400 components a week regularly and to produce as economically as possible. Four alternatives are being considered—

(1) To work A and B overtime (or in shifts);
(2) To buy a machine C similar to A and B for working parallel with them;
(3) To buy a machine D costing £1,200;
(4) To buy a machine E costing £1,600

A originally cost £500. Its overhead rating is 3/- an hour, of which 1/6 is for running charges. The 1/6 an hour fixed charges includes depreciation at the rate of £50 a year. The operator's earnings average £3 10s. 0d. a week. B is similar to A in all respects.

rather less proportionately because the larger machine should be more efficient and clerical work would be less, but without definite evidence one cannot assume that, and they may be taken to be

$$\frac{18\text{d.} \times 400}{150} = 4/\text{- per hour.}$$

The fixed charges on A and B amounted to 3/- an hour, including £2 a week depreciation. For D the fixed charges minus depreciation would be

$$(141 - 40) \text{ shillings} = £5 \text{ 1s. 0d. per week.}$$

Depreciation at 10% per annum on £1,200 + £80 = £2 11s. 0d. per week.

	£	s.	d.
47 hr. labour	3	10	–
47 hr. running charges at 4s.	9	8	–
47 hr. fixed charges	5	1	–
Depreciation at 10%	2	11	–
Special tools and installing (£65 ÷ 50) . .	1	6	–
Process cost of 400 components . . .	21	16	–

	s.	d.
Process cost of 1 component . . .	1	1
Process cost of 20,000 components . .	£1,090	

Machine E has a guaranteed output of 15 an hour. This nominal rate would probably result in 36 hours being actually required to complete 400 components, the adjustment being made as for D. Standard tools will cost £90 and special tools £40. The installation cost will be £25. In this case the operator would have to be found other duties to fill up his time, but it would not be advisable, probably, to alter the set-up of E for 11 hours a week, so it will have to be idle for that time, at any rate as regards the estimate. For 400 components in 36 hours the operator's pay would be 54/-, giving a labour cost of 1·62d. each. The running charges would be £9 8s. 0d. for 400 components and the fixed charges £5 1s. 0d. per

week as for D. Depreciation at 10% per annum on £1,600 + £90 equals £3 8s. 0d. (approx.) per week.

	£	s.	d.
36 hr. labour	2	14	–
36 hr. running charges	9	8	–
47 hr. fixed charges	5	1	–
Depreciation at 10%	3	8	–
Special tools and installing (£65 ÷ 50) .	1	6	–
Process cost of 400 components . .	£21	17	–

Since the cost per component from E is identical (practically) with that from D it is not worth considering further because of the extra money it would cost. D has the disadvantage that its probable capacity for output is not much in excess of actual requirements: a hold-up might delay general output from the shop.

Overtime in such a case would cure the immediate trouble but it would cost extra then because the output would only be brought up to normal by means of it, not increased. From the capacity point of view C would be a better purchase. It would have, too, the minor advantage that, being similar to A and B, its functioning, its tools and maintenance would already be understood. But before a decision can be made the financial aspects must be examined.

A man has been receiving £20 a year interest from secure investments. After transferring his capital to industrial shares he receives £100 a year for it, a gain of £80 a year. But he is not thereby entitled to declare, as many accountants and estimators do, that his receipts from the industrial shares are only £80 a year because the £20 came without trouble and risk. This fallacy appears in books and accounts in all directions. It arose from the desire to show whether an industrial, or, more particularly, a plant investment was good business or not. The £20 was not a natural growth or offshoot like a bud from a tree: it had to be earned. As a measure of

the effective employment of capital the device of charg ing upon it, as a cost, what it would earn if invested i safe securities is misleading. It is like a 13-inch rule use for measuring feet. Moreover, as previously stated, i money has to be borrowed to buy a machine the interes on that money cannot fairly be added to the cost of th machine. Why not pay for the machine but borrow th money to pay wages? Or the gas bill? In nearly al cases the interest should be an item in the surcharge, fo there it can be distributed most equitably.

It is assumed that buying new plant would not b contemplated unless the financial conditions were stabl and satisfactory. Since the next consideration will lea to an unexpected result it will be as well to premise, too that it applies to average cases.

When a new machine is bought to replace another i is common and natural to regard the difference betwee the purchase price of the new and the amount obtainabl by selling the old one as the true capital expenditure For instance, if a man buys a car for £500 and sells hi old one for £200 he considers his outlay to be £300. Tha is true in a limited sense; it is the method used on page 253. But unless capital is allowed to dwindle (which is a condition of instability and ruled out by hypothesis), it is misleading so far as it fails to take into account duration of service.

Production engineers should view depreciation not as a diminishing of selling value but as a consumption of useful service. A machine is worth £100 because it will yield £100's worth of service. It will not yield less and less in successive years as depreciating on diminishing values implies, although, after a time, it may become difficult to maintain its output and eventually it will need repairing or replacing. Which of these it should be may be judged on the lines laid down in the present chapter by balancing outlay against results.

A logical method of depreciation should be parallel

with these facts. On the whole, straight line depreciation by equal annual decrements to zero seems to be the best. Occasionally depreciating to a residual value instead of zero may be preferable. Money spent in repairs or reconditioning is capital lost except as the machine's value for service or sale is thereby raised to a higher level than the normal for its type and age.

A new machine M will last for, say, 10 years. The old machine N which it replaces has spent 8 years of its life and can give only, say, 4 years more. Therefore, if M were not bought, another machine like N would be required in 4 years. But only 6 of its 12 years of life would be needed to make up the 10 years equal to the life of M; consequently $\frac{6}{12}$ of its cost (or, if preferred, $\frac{6}{12}$ of the present value of its cost 4 years ahead) should be added to the present value of N to set off against the purchase price of M and discover the differences in capital outlay. It is obviously wrong to balance the 10 years service of M with the short remaining period during which N will last. Another N (or an equivalent) will have to be bought, provided that production is to continue, and its expense must be anticipated.

In the example with machines ABCD the capital outlay with scheme 1, or A + B with overtime, is nil by the short view. As compared with this, scheme 2, which introduces C, involves an expenditure of £515 but saves £43 a year. Similarly, scheme 3, using D, requires an immediate expenditure of £1,345 − £300 (the selling price of A + B) = £1,045 but saves £310 a year.

But short or partial views which consider only offsets and differences are misleading. The long view is far better. Consider, for instance, a period of 10 years and ascertain the capital consumption by the various schemes during that time. There can be no risk in taking such a long term provided standard machines are concerned and the depreciation rate is not too low.

With straight line depreciation to zero the annual

consumption of each machine will be $\frac{1}{10}$ of its original cost if its life is 10 years. Hence A + B will use £100 per annum, C will use £50, and D £128 per annum besides preliminary expenses. Suppose that A and B are 7 years old. In 3 years they would need replacing in any case, and if similar machines are assumed to follow them the consumption would remain constant.

Over the period of 10 years the cost will be—

	Scheme 1	*Scheme* 2	*Scheme* 3
Machines	£1000	£1500	£1200
Standard equipment	—	—	80
Installation	30	45	25
	£1030	£1545	£1305

Thus scheme 3 actually requires less capital than scheme 2, although the short view gives a contrary impression.

In practice the useful life of a standard machine tool is between 20 and 25 years. It will have been reconditioned twice, probably, during that period. Towards the end use will be made of it only when no alternative is available. Provided business is good, it seems better to take the long view as indicated above and scrap machines over 15 years old. It would generally pay more than appears on the surface, because various expedients have to be resorted to to make decrepit machines function successfully, and the cost of them may easily be hidden in general shop charges.

CHAPTER XII

PLANT CAPACITY AND ARRANGEMENT

In all well-organized works production programmes are arranged regularly. Usually there are long-term (or seasonal) programmes of a general character, and weekly programmes made out to suit customers' immediate requirements. Plant capacity should be arranged to suit the long-term requirements, weekly variations being got by changes in the man-hours worked. Many trades are seasonal, having a high peak load which lasts for only a few weeks in the year. The capacity must be equal to the probable peak load, unless arrangements can be made for carrying heavy stocks.

Calculations for plant capacity are founded on either the known or the estimated basic times. In the case of mixed production the actual output is commonly about 60% of the theoretical capacity and in mass production not more than 75% or 80%. Setting up, scrap, absentees, irregular material supplies, and breakdowns account for the loss. It is not that many sections of the works could not do better as a rule, but excess in one direction does not make up for deficiency in another, and it is the laggard which determines the output. The others are forced into the slow step.

When arranging mixed production plant for a given output in stated working hours it is necessary, therefore, to have an excess capacity, on the plant as a whole, of about 50% over the theoretical figure. If not, either the programme will not be kept or excess time will be worked. The qualification "on the plant as a whole" is important. If the key machines (i.e. the laggards) are specially supervised they may yield, perhaps, 90% of their theoretical capacity. It would be safer to add to their number, but not always expedient. However, the fact

that they can be made to give an unusually high yield (if they are not too numerous) lessens the total quantity of plant required. Power presses on mixed production have an extremely low yield, perhaps only 25% or 30% of the theoretical, and horizontal boring machines are often little better. Of course there are always overtime and shift working for increasing output. Again it is the key machines which must have special attention; but they will not be likely to give more than 75% of their theoretical capacity from shifts, however keen the supervision and well chosen the operators. There is a loss at every change because no two men work alike. Again, during the day men and foremen can have help and advice as they need it from the staff. Unexpected difficulties will occur, however, and at night the men and foremen are isolated with none to assist with advice or decisions. Overtime for a couple of hours a night is efficient for short periods. After a month it should be dropped for a few weeks. Week-end working is most unsatisfactory. If piece-workers can work week after week without week-end rests, or other days off, and still earn good bonus, their prices are too high. There are many firms who allow it regularly. It will generally be found that their Sunday foremen are paid by the hour.

In the case of mixed production to obtain a schedule of plant required for a given purpose the most convenient way is that shown in Fig. 53. A large sheet of paper is prepared by ruling on a drawing board, and filled in with a list of the components—represented by A.B.C., etc. The names of the classes of machines required head the other columns, being subdivided as required—if necessary by subsidiary sheets. Component A for example requires 18 hours vertical milling, 8 hours at one operation and 10 hours at another. Boring (horizontal) takes 25 hours, heavy radial drilling 10 hours and light radial drilling 25 hours. At the foot of the columns the total time for each class of machine is shown. The times in the columns

PLANT FOR MN UNIT. 100 SETS PER WEEK.

Component.	Quantity.	Planing.	V. Milling.	H. Milling.	C. Lathe.	Capstan.	Heavy R. Drill.	Light R. Drill.	Sens. Drill	H. Borer.	Ext. Grind.
A	100	50	8/10				10	25		25	
B	100		23		16			17			
C	200		14						32		
D	100			12/14							
R	4.00				42				20		
S	100					8					
Hours.		76	63	102	82	310	36	210	156	80	96

FIG. 53. SCHEDULE OF PLANT REQUIRED

may be basic time or time allowances. If the latter the conversion into basic times is easily made to the totals by multiplying by the appropriate factor, for instance $\frac{4}{5}$ if the time allowances permit the operators to earn time and a quarter. Another way of effecting the same result is to consider the real week as consisting of less than the nominal 47 hours.

In the figure, basic times are given for 100 sets of components, one set including every part necessary to build the machine or unit being studied. Whether 1, 10 or 100 sets is chosen as the basis depends on the quantities required in a week (or other period). The total amount of light radial drilling is found to be 210 hours, 50% is added to this as already explained, making the capacity hours 315. At 47 hours a week this requires 7 machines. Horizontal boring amounts to 80 hours. 50% on this makes the capacity required equal to 120 hours. Three machines may be desirable but possibly two would suffice if they were well looked after and changes of set up were few. On the other hand it might be necessary to add 100% instead of 50% in the case of these machines and then four would be required. Of course if the setting up times are provided for by enhanced time allowances for the operations, the 50% allowance is excessive. The 60% efficiency figure is based on the loss being accounted for by—

Change of set-up	15%
Absentees and late comers	7½%
Extra work, scrap, and rectification . .	7½%
Tool and machine breakdowns and short supplies	10%

It follows, if these figures apply, and when setting up is reckoned as being part of the operation, that the efficiency may be 75%. In that case a 25% increase of the theoretical capacity will suffice instead of 50%, if the key machines are served well.

It is obvious that the whole load on a works and the quantity of plant required can be found by adding together

the results obtained for each product. The difficulty is that weekly requirements are constantly changing in most works. When they are steady the weak places are quickly revealed and no elaborate charts are necessary to find them. Loading charts are useful to anticipate and prevent local overloading but it is not much use trying to invent and use schemes which purport to show continually the loading in great detail. The existing load can always be found by reviewing the outstanding production orders which the foremen have; and afterwards a fair idea can regularly be obtained by adding to the load as further orders are issued, and subtracting from it as the output and man-hours worked indicate. Yet it is desirable to review outstanding production orders at intervals as a check, tabulating results on the same forms as used for the schedules in Fig. 53. When the review is being made some orders will not have been started, some will be on the verge of completion, many will have operations completed, operations not started, and operations $\frac{1}{4}$, $\frac{1}{2}$ or $\frac{3}{4}$ finished. By considering each case on its merits, not striving after meticulous accuracy, it is possible quickly to arrive at a satisfactory conclusion.

For practical purposes it does not matter whether a section is estimated to have 1,000 hours or 1,100 hours' work to do in a week if the real amount turns out to be round about those figures, but less rather than more. To underestimate is almost a crime. The laggard section sets the pace for the whole works.

The loading of single machines may have to be ascertained in the case of large planing or boring machines, for instance; but the bulk of the minor details are best left to a good foreman to arrange as he finds expedient. He knows the men as well as the machines.

The question of tool room capacity to supply special jigs in good time may arise; it should be studied in the same way as production capacity.

Sometimes, in works where loading is not systematically

studied, overloading is not suspected before there is consistent failure to keep delivery dates. This is serious at any time because a late delivery may spoil the chance of a repeat order. It is worse in the case of export orders where, perhaps, a special ship has been named to transport the product and arrangements have been made only to be cancelled. Worse still are penalty orders where the price to be paid for the product is reduced for each week or day it is overdue.

Suppose a substantial order is received which will keep the works busy for a few months, and it is desired to ascertain whether overtime will be necessary. It is known from the figures obtained when preparing the estimate that only one section will be affected. Overtime it is desired to avoid if possible on account of the increased expense; for while necessary overtime arises because of extra production, and often reduces component cost, unnecessary overtime arises because of bad management—average production is not increased, nor is the income, but expenses are.

The hypothetical section has a capacity of 329 hours per week. The order X is to be completed in 18 weeks. It will be 3 weeks before production can start on account of getting materials and making other preparations. The whole of the machining must be completed at least 4 weeks before the delivery date to give erecting and testing a fair chance.

When the order is received the shop is already carrying a fair load and other orders are definitely expected every week. The ideal arrangement will permit all the orders to be completed at the due dates, minimize overtime, and when the large order is finished leave on the works the load due to the latest orders received.

The machines have 11 weeks in which to complete their share of the large order. This is estimated to give a (nominal) load of 1,000 hours on the section. Besides this it is expected that the small orders, coming at the usual

rate, will amount to a (nominal) weekly load of 120 hours. The effective load will be 50% greater than the nominal load on account of machine setting and the other causes mentioned.

When an order is started in production it does not suddenly come into full swing. The first operations start on some components, and gradually more and more machines become busy on successive operations until, in a few weeks, a whole works may be busy on the one order. Similarly there is a tailing off at the end: there is not one instant when all the machines suddenly complete their last little bit of the order. Consequently the 11 weeks during which the order is passing through the machines is not 11 weeks of full capacity. It will take in this case, say, 2 weeks from the start to get fully going and about the same time to tail off at the end. These 4 weeks may be about equivalent to 2 weeks at full capacity. The machines not on order X will have to be engaged on other work. If extra shifts are to be worked it will take time to get new men properly started, and every bit of the 50% allowance on the nominal load will then be needed.

Problems of this kind are best solved by a combination of arithmetic and charts. There are innumerable ways of making such charts, many of them serviceable. It must be borne in mind that the forecast and its graphic representation will turn out to be only an approximation. With reasonable luck it will be an excellent guide, but it will not be worth while to spend an enormous amount of time on it; merely sufficient to make it serviceable.

First of all tabulate what is known—

	Nominal Load	Effective Load
Order X	1,000	1,500
Running orders per week	120	180
Orders already in hand	400	600
Plant capacity	—	329

For some purposes the natural form of chart has successive weeks stretching from left to right. Here it is desirable to show several weeks, each on a fairly large scale; hence the weeks are arranged as shown in Fig. 54. Rule the frame with its width equal, on the chosen scale, to 329 hours, the nominal capacity of the plant per week. Next rule a line to represent 180 hours per week for the expected running orders, thus reserving space for them. Orders in hand will be in the load for the first week (ending September 2nd) and fill 329 hours, as shown by the thick line. But the 180 hours' reserve should not be encroached on for later weeks, it being supposed that the running orders are for standard units which must be quickly delivered. Rule the balance of the 600 hours of orders in hand in the 149 hour space. Unless material for the large order is in early, or anticipatory work can be done on expected running orders, there will not be enough work to keep the section fully loaded during the third week as shown by the space Y at the extreme right. At this stage the running order lines for September 9th onwards have not been ruled.

The machining for the large order X is to be finished by the end of the 14th week (December 2nd). It is due to commence in the 4th week, but most likely, as already explained, the start will be slow—all the machines will not be able to commence on it. But rule lines in the 149 hour space for successive weeks, leaving the 13th and 14th weeks clear.

This is reserve to allow for starting, delay, and tailing off and may be filled later on with subsequent orders. Of course a reserve of two weeks would not be sufficient for long contracts; the safe period must be judged according to circumstances, and so must the delay at the start.

Of the 1,500 hours required for order X the allocated capacity is at this stage $9 \times 149 = 1{,}341$ hours. The balance, 159 hours, can easily be got with a little overtime; for instance, 4 hours a week by each of the 7 machines

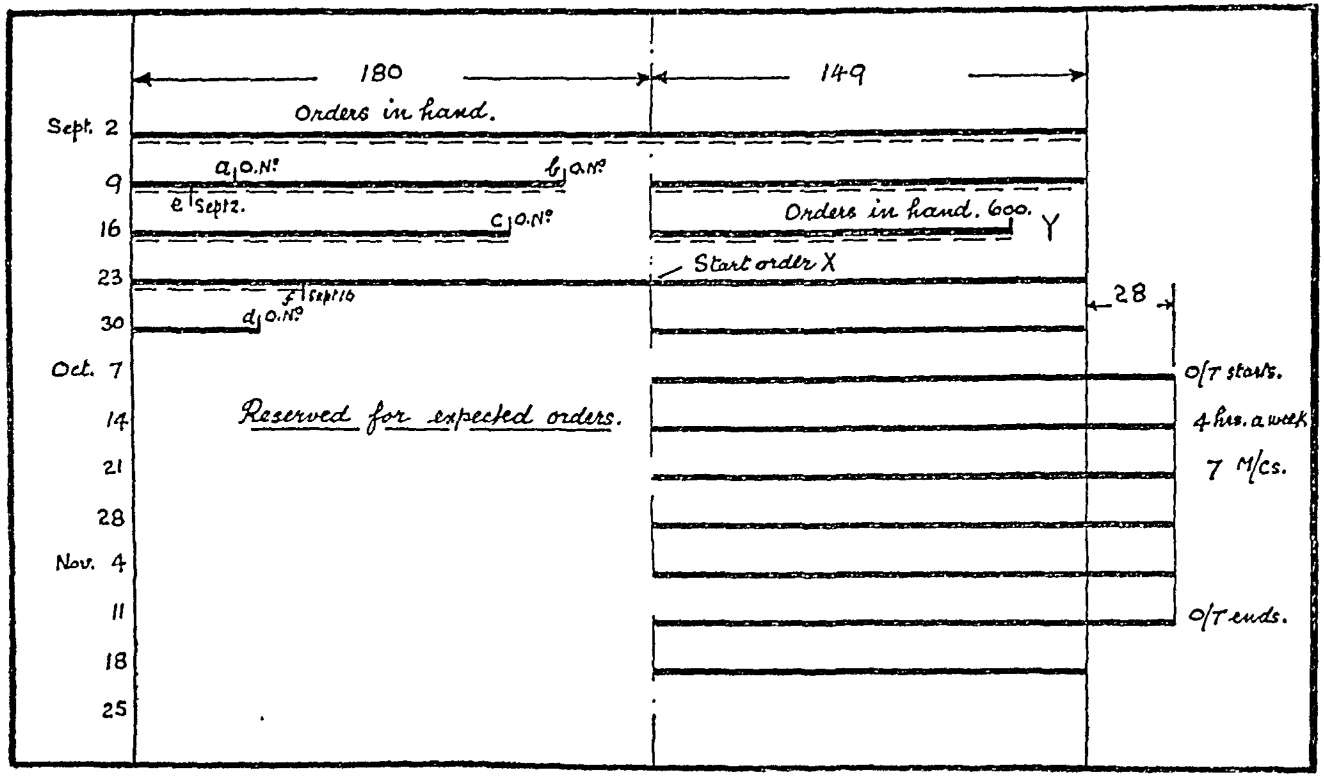


FIG. 54. LOADING CHART

for 6 weeks will give 168 hours. Rule accordingly, extending the frame as shown, not starting overtime until the 6th week to make sure there is plenty of work available, and finishing at the 11th week. Thus the whole 1,500 hours (with 9 hours over) is allocated on the chart. But the arrangement is subject to modification. Much will depend on how the expected running orders materialize; moreover it is certain that the 4th week will not yield the amount of order X allocated to it; perhaps not the 5th week either. It will be necessary to watch events and decide later whether 4 hours overtime is sufficient, but it should be with the amount of reserve. With a charted plan as a guide events can be better marshalled. Without it necessary overtime may not be started until too late to save the work from becoming overdue, or overtime may be commenced blindly, the men being gathered together of an evening with insufficient work to keep them occupied—a common fault.

The chart is drawn as it appeared on September 20th. If an order could be started suddenly at full output and stopped as quickly as the load lines indicate, overtime would be unnecessary in this instance. As a rule, in practice, one order is worked in with another so that the load lines do show very well how matters stand on the whole, though not exactly what the situation is as regards any particular order.

As the running orders came in (it is supposed that raw materials were kept in stock, ready) lines corresponding to the loads due to them were drawn in the reserved space. It will be noted that at (*a*) these orders came in in excess of capacity and were carried on to the following week, the order number being written in for identification. But the orders fell short the next week as shown at (*b*). This space must be left vacant because when other orders followed they were too late for the capacity to be utilized. A load cannot be assigned to a date already past. Similarly at (*c*) there is a shortage and at (*d*) an excess carried forward.

As the work is done, and production orders pass through, the amount of work they represent can be cancelled as indicated by the dotted lines and terminals at (*e*) and (*f*), the dates being inserted. In this way the chart may continually show the existing load and whether general progress is made at the desired rate or not. For this purpose the cancellation as work is done takes no account of which orders are done. The chart is not intended as a guide to the progress of particular orders, but only as a load indicator. As drawn, the chart shows the work to be ahead of schedule, the work for part of the 4th week having been completed on September 16th as shown at (*f*).

It is extremely irksome, and therefore likely to increase mistakes, for calculations to be based partly on actual operation times or time allowances, and partly on the nominal capacity or actual number of hours worked. In the last example the nominal machine hour capacity determined the scale. Operation times, whether for new work or for work which had been executed, were reduced to that scale by arithmetic before the appropriate lengths could be ruled or cancelled.

A method of avoiding this arithmetic will now be shown. Similar methods can be applied to any of the common systems of payment by results, but that described is for the piece-bonus system, that is piece-work with time allowances instead of money prices. This system is widely used and is growing more popular.

A given length may represent 100 hours on one scale, 120 on another, and yet a different quantity on a third scale. It is convenient to measure shop capacity by the man-hours nominally available—on one scale. The amount of work done as expressed in P.W. time allowances can be measured by another scale bearing a relation to the first such that it gives direct readings of piece-bonus times although applied to lengths representing nominal shop capacity.

Suppose, for instance, that 100 hours piece-work time

illowance which enables a man to earn $1\frac{1}{4}$ times is to be charted in this manner. The actual effective working time would be 80 hours. The shop load would be 50% above that (more or less according to the shop efficiency), or 120 hours. A line 10 inches long may represent 100 hours P.W. time allowance, one hour being 0·1 inch long.

Also if one hour is represented by a length of $\frac{1}{12}$ inch on another scale, the 10-inch length will include 120 divisions or hours on the second scale.

Now the 50%, or whatever the figure may be, is more or less arbitrary; it is not a scientific assessment but a rough and ready compensator. It follows that it need not be strictly adhered to if a small deviation considerably simplifies the arithmetic. For instance, on the above scale 47 hours would be represented by $\frac{5}{6} \times 47$ hours of time allowance, which equals 39·17 hours, quite an impossible figure to work with, and 40 hours is near enough for the purpose.

In the next example the double scale method is used. The perpetual loading scheme is also incorporated. But it is usually simpler and better to construct new charts at intervals of about 3 months, each being ruled for 6 months. As stated previously, records of this kind do not remain approximately correct for long unless adjusted with reference to production orders. Records of scrap and rejects may easily be overlooked and these alone will impair accuracy.

The chart in Figs. 55 and 56 is for a section containing 10 machines with a normal capacity of 470 machine-hours per week. At the start there is a load of 1,834 piece-work hours and an order X which will give a further load of 1,750 hours, to be started in the week ending July 8th, the completion date being October 7th. The first thing is to construct a scale as shown at the top of Fig. 56. It will be useful for all charts to be made on the same basis so it is as well to draw it on paper and then gum it to a thin-edged lath. The edge A is spaced in proportion to

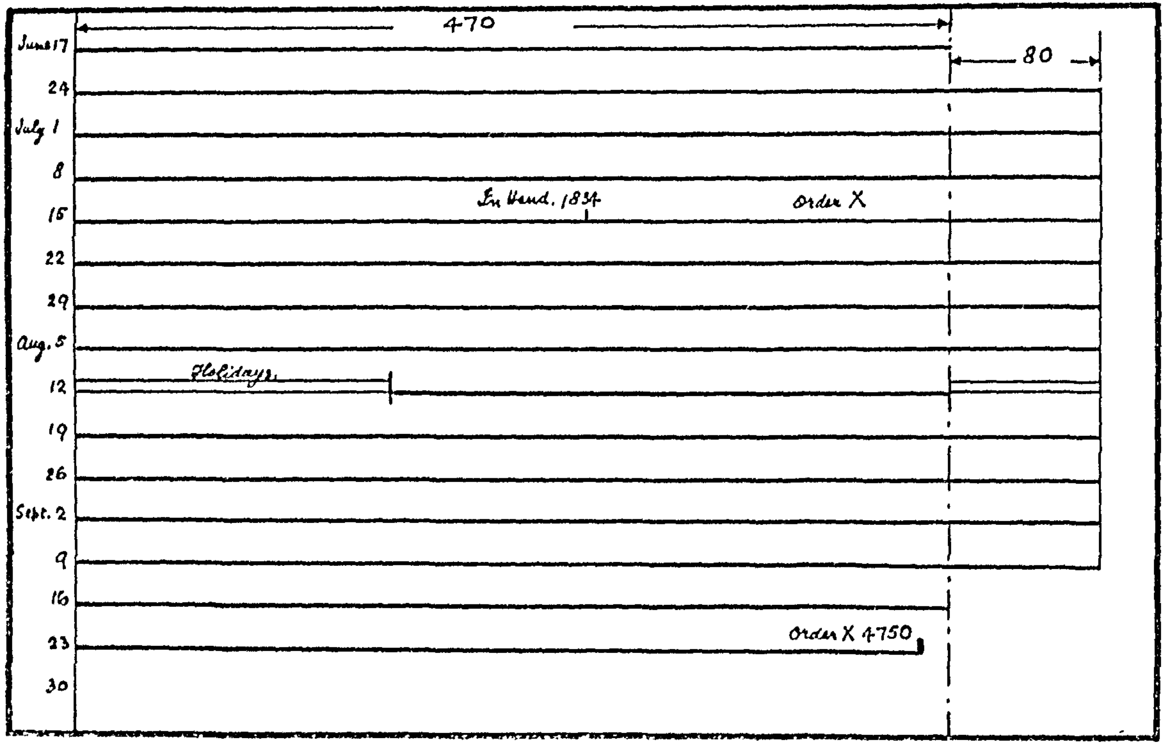


FIG. 55. LOADING CHART

piece-work time and edge B to nominal machine (or man) hours. That is, a length on B representing 47 hours or one week of full time on one machine represents on A the number of piece-work time allowance hours which the man would actually earn during that week, on the average, after making all allowances as previously described. In the Figure 47 hours on B occupy the same length as 40 hours on A which is, at present, a commonly satisfactory relation for the purpose. The maintenance of the chart will soon show whether this ratio requires adjusting or not; and if the week be not 47 hours, or shift working is the rule, or some other method of payment exists, the scales should be constructed to suit, bearing in mind that it is desirable and justifiable to make minor adjustments which will simplify any associated arithmetic. For Fig. 55 draw the frame 470 hours wide with scale B and enter dates against the left-hand datum line. With the same scale set off the holiday space for the week ending August 12th. Then, with scale A draw lines within the frame to represent 1,834 hours for orders in hand. The next step is to arrange for order X to be duly completed. It will be advisable to reserve the last two weeks free for clearing up oddments and to balance the slow start. There is plenty of time to get materials in and the machines can be kept fully employed, X gradually occupying them as the previous orders are completed. Rule lines in the frame to occupy all the vacant capacity up to and including the week ending September 23rd. The combined length, measured with scale A, comes to 5,855 hours, but the total load is 6,584 hours; hence extra capacity is needed for 729 hours. This is not much. It will not be advisable to commence overtime immediately, perhaps. Let it start the second week; that will enable extra material supplies to be obtained. The overtime should end, say, a fortnight before September 23rd. This leaves two extra weeks for it if necessary. There are thus twelve weeks' overtime, nominally, but one is holiday week, scarcely suitable for

already scheduled above that. Again, it would be unsatisfactory to commence the double shift before the holidays. Moreover it would be inadvisable to attempt to start 10 "green" hands at once. They could not be properly looked after. Let it be decided to start 5 for the week ending August 19th and 5 a week later. This will mean one week when part of the section is working overtime and the rest of it by shifts—an unsatisfactory arrangement, but probably the best in the circumstances. As scaling the chart will show, this gives the following increases in capacity—

1st week (19th Aug.) . .	108 hr.
2nd "	216 "
3rd and 4th weeks . . .	432 "
5th to 9th weeks . . .	1,425 "
	2,181 hr.

This is sufficient. Therefore let the double day shift end on October 14th (subject to progress being as expected and no further orders arriving) and mark off orders Y to finish 181 hours short of the end of the week dated October 28th, or, if desired, the 19 hours left at the end of order X can be added, making a total of 200 hours to be deducted from that week's load.

When there are numerous jobs to be completed at different dates the chart is just as useful. It shows the total load: it is not an essential part of the chart to have order numbers indicated, merely a convenience to ensure that all orders are booked and none duplicated. If a small rush order arrives when the chart shows a full load extending beyond the delivery date of that order there is no need to increase capacity if some of the other orders may be deferred. The load lines will be continued as required but the rush order will have preference in the shops as called for by the progress men, whose work will not here be considered. It may be said, however, that planning ahead is far more effective than ordinary progress work and reduces the latter to small proportions. A push

at the start is worth ten tugs at the end. Progress work without adequate planning is akin to dragging an overdue lorry which was not provided with sufficient petrol to drive it to its destination.

The worst trouble encountered with a suddenly increased capacity is usually (apart from possible difficulties with "green" labour) in obtaining materials as required. Several sources of supply are always an advantage, and if the planning be tackled immediately, in conjunction with the stores, so that the buying office staff is given adequate time there need seldom be any but minor delays. The work is purely clerical routine for the most part, special attention being given to items which it is anticipated (anticipated, not discovered later) will need it.

It is not always worth while to make capacity charts except for the sections or groups of productive units which require such consideration. On the other hand, where work is fairly stable in character, one chart will serve for a mixed machine shop if the key machines are well and separately studied.

The difficulties of planning and progressing are enormously increased if there is no piece-work or other system of payment by results. Unless piece-work times are inflated by excessive allowances for delays (which in a better managed shop would be far less) the operator's earnings provide a rough measure of efficiency. Besides the danger of hidden excessive allowances, there may be numerous allowances made on supplementary tickets for various reasons, many of which would not survive competent investigation. It is therefore always worth while keeping a tight hand on the issue of special tickets for extra work, that is work which was not planned for and is alleged to be due to excessive material to remove, hard material, poor tools, and so on. It is quite easy to run a piece-work system in name with daywork conditions, in fact, by allowing extra pay as men ask for it, foremen and

rate fixers being too kind. Moreover it is not difficult for the latter to prove their case to managers less technical than themselves.

Many works need not three, but four machines to get the output which two could give under ideal conditions; and this even when setting up is allowed for in the operation times. The deficiency is often attributable to the lack of planning.

In the case of a mass production plant variation in the volume of the weekly output is got by altering the hours during which the whole plant is worked. But even then the capacity is rarely uniform in every part, and strengthening two or three weak places may enable the whole capacity to be greatly increased. The strengthening may be effected by selecting operators of more than ordinary speed, by improving the methods of working, by adjusting the distribution of the work, by adding extra machinery, or by replacing existing machines by others of larger capacity.

The first is precarious and temporary, though it often suffices for a short season; the second and third are useful; but if a substantial increase is desired it is better to expend money on standard new machines than on new special tools.

In mixed manufacturing the machines are grouped functionally, that is, according to their kind, drilling machines together, milling machines in another place, and so on. This is the best plan for that purpose, it being impossible to group them in any other way which would permanently suit. It has the advantage of specialist foremen, men who have a thorough knowledge of the machines or process they supervise (an advantage which is often overrated) and it minimizes the quantity of small tools in use.

For true mass production the machines are grouped to suit the components, each group being arranged and

placed in relation to the whole in such a way that the flow of production is continually convergent, and transport is minimized. Most of what is termed mass is really intensive production. Intensive production is a mixture of mixed and limited mass production; mass production methods are applied to some components and assembling; other components progress without a well-defined flow—they return on their tracks or share machines with others—the remainder are made by mixed production methods.

For example, in an automobile factory the large or more numerous components may have a definite mass flow; beginning as raw castings or forgings at one end of a line they emerge at the other finished for the assembling conveyor. Other components occupy a group of machines too little for exclusive allocation; the group has to deal with several kinds or sizes. There may be a fairly well defined flow in one direction for some (but not all) of the components, and the set-up of the machines has to be changed at intervals. Because of the nature of the processes involved, or small quantities, others are treated exactly as in mixed production, the only difference being that fairly large quantities may permit more efficient tools to be used. For instance, sheet metal components may be blanked on one press, then raised or formed on another some distance away, both presses having to work at times on other components. After this they may go to the bench workers, then to welding, back to the benches, and finally be sent to the enamelling department, whence they emerge ready for assembly. Multiply the quantities to be made by 100, and then it might be worth while arranging for line production.

One problem which arises now and again deserves study on account of the various issues. A works is engaged in the manufacture of one type of product but in several different sizes. Each product is built up of units or sub-assemblies; the units vary for the different sizes but many of the component parts of the units are common to several

sizes. What is the best type of general layout for production?

If the quantities to be made are small the answer is easy: unless the machines are arranged functionally, as for mixed production, it will be extremely inconvenient to load them efficiently without gross waste in transport. When the quantities are large the correct answer is not easy to find. Much depends on what is meant by *large*. To keep bar autos. and power presses efficiently occupied needs what may here be termed very large outputs estimated in thousands per week, or, at any rate, at one set-up. On other machines the weekly output may more often be measured in hundreds. So a large output is, for the present purpose, one which is measured in hundreds per week, because that will enable the machines to be arranged for efficient line production if desired. There are, however, processes such as gear cutting, polishing, plating, heat-treatment, and painting which it is preferable to keep in isolated departments, partly because they can deal with very large quantities, but also because they require special technical supervisory knowledge, or auxiliary apparatus such as exhaust fans which it would be wasteful and inconvenient to install here and there amidst other machinery.

With the above exceptions the machines for a large output may be arranged in three principal ways:

(1) Functionally as for mixed production.
(2) For the intensive production of the units, each kind of unit having its own separate plant.
(3) According to the main products, each size having its own separate plant, the parts common to several sizes being all made in that section where the majority are to be used.

With large volume production the first plan has the advantage of keeping the machines well occupied; but here is too much transport and too many changes of set-up or it to be economical. The planning and the progressing

become complex, and assembling, in consequence, is not likely to be regularly supplied unless heavy stocks of raw and finished materials are maintained. There is some advantage in specialist foremen, but not very much. It is much more important for the milling foreman to be a good organizer than it is to be able to work a milling machine incredibly fast, or milling extraordinary shapes with ordinary tools.

The second plan involves, for efficiency, line and intensive arrangements. The foremen know well the functions of the units they produce and of all the parts in them. That is better than their being expert machine demonstrators. Each foreman controls a variety of machines, but the production of only one kind of unit. The total quantity of plant may be slightly greater than required or the first plan because not all the machines can be fully occupied. The increase may be small because of the reduction in the number of changes in machine set-ups. Planning and progress work become much easier, the work being concentrated and those engaged on it being more familiar with their local circumstances.

The third plan also depends for efficiency on line production. Owing to the comparatively small load on each line many machines cannot be fully occupied and more plant becomes necessary. Planning and progressing are extremely simple; it is easy to maintain regular supplies for assembling, without carrying excessive stocks. There are few changes of set-up required and the efficiency per operator is high. It is not difficult to foster a competitive spirit between neighbouring teams engaged on similar work, and this can be directed to improve quality and quantity. Perhaps the worst objection to this plan is that the increased plant (not forgetting the large magnification in the number of small tools) would be a much heavier burden than in either of the others if business became slack. On the whole, the second plan is the best unless a large trade is assured for several years, when the third

is the most economical, always supposing that each line can be loaded sufficiently.

Once the load enables most of the machines in line production to be approximately fully occupied during normal working hours the peak of efficiency is nearly reached. Two shifts a day are better than one and three better than two, but not very much. Neither is mere magnification of the load and plant of great benefit.

Were this not true only large works could survive, and small works would never grow. Magnification and rationalization are not entirely good. The economies which may be gained by large volume production can easily be more than offset by losses due to the diluted vitality of the management.

When planning a workshop layout the first thing to settle is the direction of the flow, i.e. the end at which raw materials are to enter and where the finished product is to emerge. The best choice is that which minimizes transport. When this has been settled the main gangways may be marked on the plan. The size of these depends on whether the work is small or large, principally, but also on the size of the shop. There is more traffic in a big than in a small shop and the gangways must be made to suit. For small shops engaged on light work a 6ft. main gangway is wide enough; 8 feet is better for a large shop and 12 or 15 feet if the work is heavy.

Secondary ways may be 4 feet wide. A good deal depends on the trucking system. If it is desired to have a tidy-looking, well-ordered shop, the gangways must not be stinted. A cramped, higgledy-piggledy layout is rarely efficient: it makes for losses due to slow traffic and damaged components.

It is inadvisable to let benches butt endways against a wall or for machines to be quite close to them. Even a narrow way 18 inches wide will prove both a convenience and a protection against accumulations of rubbish.

There is less objection to benches backing against a wall. The floor space under benches should be kept quite clear for the sake of cleanliness.

Machine arrangement has to be decided first according to the type of production (mixed or intensive) and then to suit the line shafts and gangways. Room must be provided for inspection and marking-off tables. Machines with self-contained electric drive are most convenient, particularly for intensive production; being independent

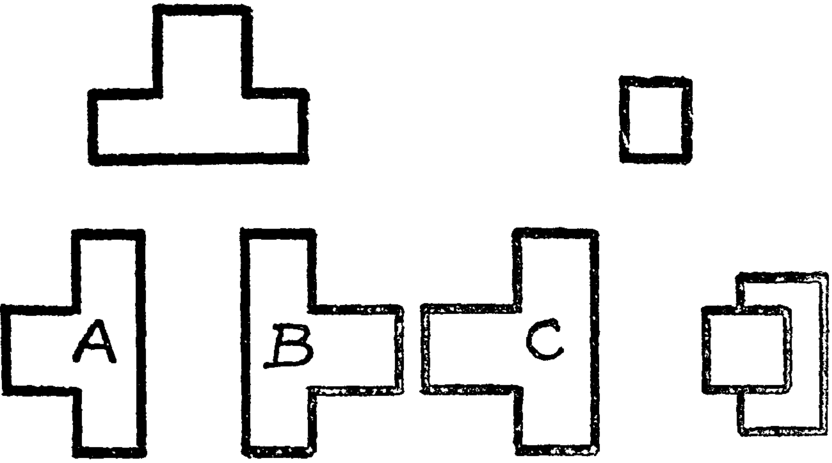


FIG. 57. LAYOUT FOR INTENSIVE PRODUCTION

of lineshafts they can be arranged more economically as regards space and more conveniently, sometimes, for operating. For example in Fig. 57 there are two groups of machines, one of 3 milling machines and next to it a milling machine associated with a sensitive drilling machine and a drilling machine with a multi-spindle head. Shop regulations permitting, one man can serve the first group, if the cuts are lengthy, and another the second group. The output per machine may be lessened, but the works cost per component slightly reduced. Such arrangements are not suited to mixed production. Milling machines set as at A.B.C. with about 4 feet between the nearest edges of the slides as shown for A and B and

with B and C back to back save floor space with the arrangement in Fig. 58 at A.B.C. T can be applied to some other machines.

When machines such as lathes are plac production they may stand with a few ir between them at the ends. The exact amou partly on what mechanism is situated at the partly, when they are line shaft driven, on tl pulley positions on the line shaft. The averag engaged in light medium production measu 3½ feet from back to front, ignoring small project as handles. Two feet is a fair space for the Thus the total average width required is 5½ feet. with stanchions at 15 feet centres there is com room for two lines of machines. Allowing 1 f missing the stanchions the arrangement results in way 3 feet wide. In practice it appears wider t the operators are only stationed at intervals. Simi 30 feet wide bay enables 4 lines of machines to be the combined width of the two gangways amounti 7 feet since there are no central stanchions. With wo a rather larger kind or for mixed production three lin machines is the most that should be set in a 30 feet and two lines in a 20 feet bay.

This spacing gives plenty of room for trucks and fl space for components when production is mixed. a rule, line or intensive production wastes little floor spa with idle components, but exceptions do occur and pr vision has to be made for them.

The tendency to an increased number of machines i line production is offset by avoiding changes of set-u and the increased dexterity of the operators. The floo area occupied is much less. With mixed production the components are taken from one pile, worked on and laid on another. Space has to be allowed not only for these piles but for trucks to travel between. In line production the machines can be packed closer together and the

gangways between the lines need only be sufficient for the operators' convenient working.

In mixed production the inter-operation trucking service often makes a complete round but once a day. As a consequence there is, on the average, not less than a full day's work against each machine. If, to take a simple example, a component requires 6 operations to complete it and each operation can be done at the rate of 100 a day, there being one machine for each operation, it will take 6 working days for a component to pass through and there will be 600 components in circulation together (supposing, of course the batch quantity to be not less than 600). In line production with the same speed at each operation the number of components in the line will be about 12 (allowing one in process and one waiting for each man) and the time from the start to the finish of a particular component may be 30 minutes. In both cases there will be reserves of raw and finished components at each end. The reserve at the finished end can be much smaller for line production because a shortage can be quickly made up. A breakdown through failure in supplies of raw material with mixed production does not necessarily hold up assembling for 6 days, for special arrangements can be made for rapid transport. Still, such expedients cause wasteful commotion and cannot, economically, become common.

The routes taken by components in mixed production form a maze if charted on a plan. In Fig. 58 the tracks of 4 components are shown from their emergence from the rough stores to delivery at the inspection cubicle. With functionally arranged machines transport must be a heavy expense. It is often possible to save some of it, here and there, even when there is not much repetition work done. The four components kept fully occupied the machines indicated in the figure. By adding two more machines and re-arranging as in Fig. 59 the production was increased by 20% and the inter-operation trucking,

as a separate expense, was practically eliminated. The saving in floor space is also notable. What cannot be shown in the figure, but is, nevertheless, a very real gain, is the ease of quantity control. There are only 4 points to feed in Fig. 59; the subsequent flow is automatic. But in the earlier arrangement each move between the

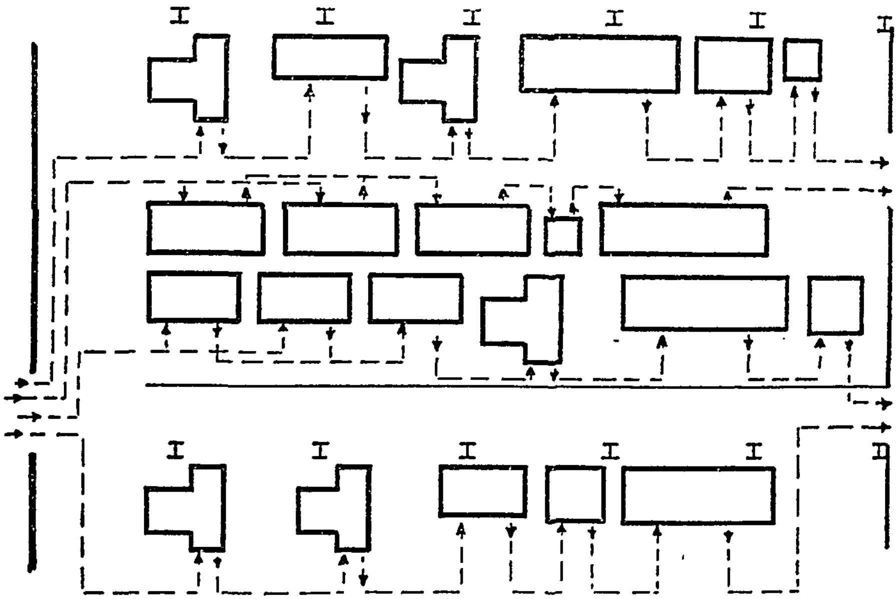


FIG. 59. SHOP LAYOUT—LINE PRODUCTION

machines had to be watched and ordered—at least 16 points altogether.

Small machines driven independently could be made portable very easily. When well balanced, as most good quality machines are to-day, they might even be on castors. Perhaps jack screws at the 4 corners would be desirable, but with stiff frames it is likely that 3 castors or 3 feet well splayed would be better than 4, being stable on an uneven floor. Another way of assisting portability or semi-portability would be to standardize floor fixing dimensions as regards width. There might be, for instance, sets of two rails about 30 inches apart along the bays on which the machines could stand, their bases being made

to suit. Grouping the machines to suit the flow of the components is so definitely more efficient than the functional arrangement that it is worth while trying to approximate to it even for short periods. The expense and difficulty of shifting machines will soon be reduced once this idea gains ground that they may be regarded as portable tools and that it is better to move half a dozen machines a few yards than thousands of components many miles. Worse than the transport is the ordering and handling: 75% of the troubles in these would be saved.

APPENDIX

THE ELUSIVENESS OF ACCURACY

INACCURACIES of the kind commonly called "errors of workmanship" may be divided into four classes. They are caused by—

(*a*) The workman—his personal equation;
(*b*) The nature of the materials worked on;
(*c*) Defects in the tools employed;
(*d*) The conditions under which the work is done.

In the following essay only (*b*) and (*c*) receive consideration. Examples of instability are given, but the main theme is the location of work in jigs and fixtures.

Deformation of Components caused by Inaccurate Setting. No setting can be perfectly accurate. To start with, there are errors in the fixture and the work. Dirt may enter between locating faces. When a machine tool is new, it may be almost perfect; but after a time slides wear, tables droop, and bearings become slack or wear out of round. Moreover, the pressure due to even a light cut causes some deflection in the machine and in the work.

If a faceplate fixture on a lathe is required to be true, it must either be set by adjusting screws or shims or be finished in position. Remove it and replace it after a week or so and it will probably require a new setting.

Again, jigs and fixtures are finished in the tool-room to a fine accuracy (very often unnecessarily), but after service in production—well, examine a few.

Self-centering chucks are not self-centering. The jaws may be ground, for instance, to receive a short, solid cylinder, but they will not hold it dead true. Try it, and when testing with a clock indicator observe particularly the wobble on the end face. Collet chucks are better, but

insert a bar in one and turn a short length true. Loosen the chuck, give the bar a twist, and apply a clock indicator to the turned part about 3 inches away from the collet.

No one expects extreme accuracy from milling or planing. If it is required, scraping or grinding should follow. For a special purpose there is nothing to prevent great care being taken in setting a milling fixture and the arbor and cutters to obtain a very fine degree of accuracy; but that is not ordinary practice except, perhaps, for one application—gear cutting.

Strains through Clamping or Locating Forcibly. Of course, it is impossible to clamp without any strain. The nearest approach is when the work is held positively in all directions with no reliance whatever on friction. Then it may be held securely with the lightest of contacts. The moment clamping pressure is exerted the fixture yields, the component is deformed, and the clamp suffers. (A common fault is the use of clamps which are far too light and flexible. They take longer to fasten than stiff ones.)

Imagine that a flat plate is being clamped to a flat face on a fixture by three bolts. If there are holes in the plate through which the bolts may pass, there will be little deformation (if the flats are flat and clean), because the force is localized and sets up no bending action. But if the bolts are outside the plate in conjunction with finger clamps, there will be bending. Only by making the fixture stiff can this deformation be kept tolerably small. A little bending may not be detrimental for the purpose in view. Still, it will occur; the flat faces will be flat no longer.

Years ago, in early experiments attempting to measure the tidal bending of the earth's crust, the instrument was mounted on a massive concrete foundation. What could be fixed more firmly? Yet the needle swung if a man standing several yards away changed his weight alternately from one foot to the other. Now, the earth is a

casting with thick walls, so what happens to the walls of castings such as are commonly used for fixtures? It is worth thinking about. But there will be little trouble if bending be avoided or proper precautions taken to minimize the effect.

Thin cylinders may be held without much deformation in chuck jaws which almost completely envelop them provided the diameters agree. Bending will occur if the diameters differ or if the envelopment is partial. If the cylinder be bored when deformed, the hole in it will not be round when it is freed from the chuck. Deformation through holding is seldom sufficient to give a permanent set, for that would soon be detected. It is only troublesome because the locating surfaces are shifted from their right positions in uncertain ways and by unknown amounts, and many do not realize that movement occurs.

Strains Due to the Processes Themselves, such as those from heat-treatment, are generally allowed for and corrected afterwards. A bar which is straight before heat-treatment may be bent during the process and need setting before machining is continued. That the diameter has changed irregularly may be shown by closer examination.

A long rack was required for a rack and pinion gearing. It was made from bright rolled square bar, and after the teeth were cut in one face and the clamps released it took the form of a bow. Normalizing beforehand cured that tendency. Any material which has been worked severely is full of stresses. Heat-treatment releases them as a rule, but may introduce new ones. Sometimes the stresses release themselves gradually, taking a long time, even years. Now and again one hears of a large flywheel bursting because when it was cast one of the spokes was left in severe tension—not enough for it to break immediately, but after long service. Consider the parabolic reflectors used for motor-car lamps. They will not retain

their accurate shape if merely drawn in a press. Spinning them afterwards not only takes out any puckers left by the press tools but gives greater stability, probably because the stresses are then distributed in a more regular pattern. That is a point to keep in mind for other applications. It suggests an explanation for something entirely unrelated; the practice of taking forming cuts with the back tool-post on a turret lathe. There is less liability to chatter when the tool is at the rear. Consideration of the way the forces are opposed and balanced shows why. In general, if the principal forces act mainly in one direction, chattering is unlikely. But where there is slack (as in a bearing), and large forces act oppositely, a slight upset of the balance may cause violent oscillation.

The ageing of castings is well known to be desirable. Here is an experience which shows how skin stresses have sometimes an unexpected effect. A shaping machine was bought to be converted into an experimental gear shaper. Being cheap and rather nasty, the machine had to be rebuilt. After the bottom face of the ram had been re-bedded to a surface plate, it was decided to alter the front face which carried the tool-box. This necessitated machining, and when that had been done it was found that the bottom face of the ram required levelling again. Removing metal from the front caused a disturbance extending more than an inch back.

The Design of Jigs and Fixtures may be studied in books and periodicals, in offices or in workshops. It is not within the scope of this book. But the subject of location is on the border-line between planning engineers and tool designers, and a brief account is given here in the hope that it will be generally useful. The treatment is on new lines: the theory of six-stop location seems never to have been developed logically before. It is practical because it is true and useful, especially for quickly examining designs for fixtures. Moreover, the theory is

combined with suggestions for simple experiments (easily made in any workshop) which should make it interesting and at the same time impart a real understanding of fundamental principles and difficulties.

Location of Rough Surfaces. Location for the first operation on a casting or forging must of necessity be on rough surfaces. It is a sound rule to choose for the purpose, when possible, surfaces which it is not intended to machine subsequently. By following the rule, better symmetry is gained in the finished components than might result otherwise. A good example is a piston to be used in a petrol engine. The inside is rarely cast true with the outside skin, but in the finished piston evenly thick walls are wanted. It is seldom possible to machine the whole of the inside. Consequently for the first operation the inside is located on a special chuck to hold it true while the outside is turned.

If a stamping or forging is to be held in a chuck for the first major operation, the surface which one would prefer to grip may be eccentric through the flash. Moreover it may be desired to eliminate the influence of varying flash thickness. In that case a minor or preparatory operation would be introduced for turning and facing in the desired places ready for holding in the first major operation. The location for the minor operation would be as just described—from black surfaces which are not to be machined but which should be substantially true with those which are. The minor operation is used to transfer what is an unsuitable location for the major operation to a more reliable place which will produce a similarly symmetrical result.

Location on Machined Surfaces. Once surfaces have been machined, accurate location may be effected from them. Those for the datum or principal location are prepared as early as possible in a sequence of operations, and that location is used throughout the series of jigs and fixtures involved, unless a good reason exists for

departure. There is some error at every setting, and this has to be considered. A component may have a feature A whose relative position to feature B is more important than its situation in regard to the datum location. If both features are machined in one jig at one setting, their relative placings will be very nearly right. But if A is finished first and B at a later setting or in another jig, they may be correctly placed in regard to each other, or the amount A is out of position relatively to B may be the sum of the error in the placings of each with respect to the datum location: if A and B are both, for instance, 0·003 inch out of place with regard to the datum, their relation to each other may be perfect or 0·006 inch wrong. Again, the original datum may not last throughout all the operations. For example, one may locate at first off a turned diameter and face and still have machining to do after they have been ground. Perhaps a hole was bored true which can be used for locating while grinding, or there may be another suitable way of transferring the datum to another place when desired. It is a transfer of precisely the same kind as that between the minor and major operations just described. The grinding may be done with extreme care, but in the process of transfer the accuracy of the relative positions of some of the features of the component is likely to be lessened.

A datum location is invariably chosen for its reliability. Convenience may not be overlooked, but accuracy is the main essential. When possible the datum location should be that by which the component is joined in assembly to its principal mating part.

Stops and Clamps. To locate a component in a jig or fixture completely and positively it must be held in three directions, corresponding to the three dimensions of space. First, it must rest on a base or seating. Next, it must be prevented from sliding sideways. Lastly, end motion must be stopped.

If the location is positive, the component's position

is fixed by location faces for each direction. For brevity these faces will be called *stops.*

The purpose of *clamps* is to hold the component firmly against the stops. Sometimes, as will be seen later, they are called upon to do more.

A stop should have an area large enough for durability and to avoid marking the work, but so small that its directive action on the component coincides practically with that of a point.

A stop may possess any convenient shape, and, provided no directive action is introduced thereby which would cause strain, the area may be greatly extended: a set of stops may join up to form one large face.

For stability the base used for primary positioning should be widely spread. Small-area stops suffice in the other two directions. As will be shown later, they are better small.

Consider a block shaped like a matchbox: one of the largest faces is the obvious choice for the base. It can slide anywhere on that until squared and positioned sideways by a long, narrow side. Lastly, a stop at one end halts it finally and positively.

This is the parent method—all the kinds of location in use are its offspring, with variations in detail but not in principle.

Components can be held in jaws by friction without a positive stop or be partially stopped. Similarly, if firmly clamped to the base and located sideways, the matchbox can be held without an end stop. But then its position is somewhat uncertain—which may not matter for the purpose in view.

The Six-stop Principle of Location. **Any component can be completely and positively located by six stops. With fewer than six the location cannot be positive; with more than six the extra stops are redundant and are either useless or troublesome.**

For flat faces the stops should be disposed thus: three

for the base, two for one side, and one for an end. With the base there can be no doubt: nothing can rock on three legs, even if their lengths are unequal. On four legs rock across corners is invited—until clamps prevent it by strain.

Three stops for the side location also invite strain. If they are in line, the middle one may cause rock; if they are triangularly placed, they form a base to quarrel with the first. Similarly two end stops will at the best be no better than one, and may cause trouble by trying to upset the more fundamental locations.

It follows that while the base stops may be extended to occupy a large face, this is bad practice with the others.

If a large area is desirable for their durability it should be long and narrow, the length being parallel with the base, and, if possible, near it to enhance stability. Cylinders rest securely on four stops—a pair of vee blocks, for instance. Otherwise the general principles apply, as will be seen later.

Three stops are ideal for a flat base, but to locate a face which has been turned in a lathe they may be extended conveniently and safely to form a ring. A face which has been milled or shaped is not quite so suitable for ring location, for a reason which students may discover for themselves by experiment. Of course the tripod is equally useful for a stepped base on a component, the stops being set at suitable unequal heights to level it.

Now consider the extreme case of a ball. It sits firmly on three stops, yet, in an academic sense, is not positively located. Being a ball, it has no features on which further stops can act. Being a ball, it doesn't matter anyway. And a clamp will hold it by friction. Now paint a line about one inch long on the ball and set that to bring the line to a specified position. It will have to be brought round, by twisting on the base, to the desired height; the line must be set sideways; its ends must be levelled.

Movement in three directions requiring three more stops. When six stops are in action with their respective clamps there can be no sliding on them. But in the case of a ball or a cylinder six stops cannot be applied, and friction must be used to prevent sliding.

The methods of location used for holding components in fixtures nearly all fall into one of the six groups listed below—

(1) Flat base, 3 stops. Side location, 2 stops. End location, 1 stop.

(2) Flat base, 3 stops. Position on base by spigot or the equivalent, 2 stops. Friction to prevent twist.

(3) Flat base, 3 stops. Position on base by spigot, 2 stops. A sixth stop to prevent twist. (See Fig. 60.)

(4) Cylindrical base, 4 stops. An end stop. Friction to prevent twist. (Four stops for a cylinder, because the base location would be perfect on two vees.) (See Fig. 62.)

(5) Cylindrical base, 4 stops. An end stop. A lug or a dowelled hole for the sixth stop, which prevents twist.

(6) Cylindrical base, 4 stops. A radial hole or a notch or a lug which enables both end and twisting motion to be stopped.

There is scarcely need to cite examples: they abound. However, here are a few—

Group 1. Any component with a flat base and which is not round. (See Fig. 60.) A rectangular bed plate.

Group 2. Most turned components. A flange for a shaft coupling.

Group 3. Most turned components. The same flange after small holes have been drilled.

Group 4. Round components supported in vee blocks or held in self-centering or collet chucks. In the case of a three-jaw chuck, one of the jaws may be regarded as a clamp and the other two as stops. The grip is frictional, not positive, which partly explains why chucks are inaccurate. With a collet chuck the end stop is often

attached to the turret on the machine. The end stop with vee blocks either has to be attached or friction relied on.

Group 5. A flanged shaft with holes in the flange.

Group 6. Is not so common as the others. It is used for

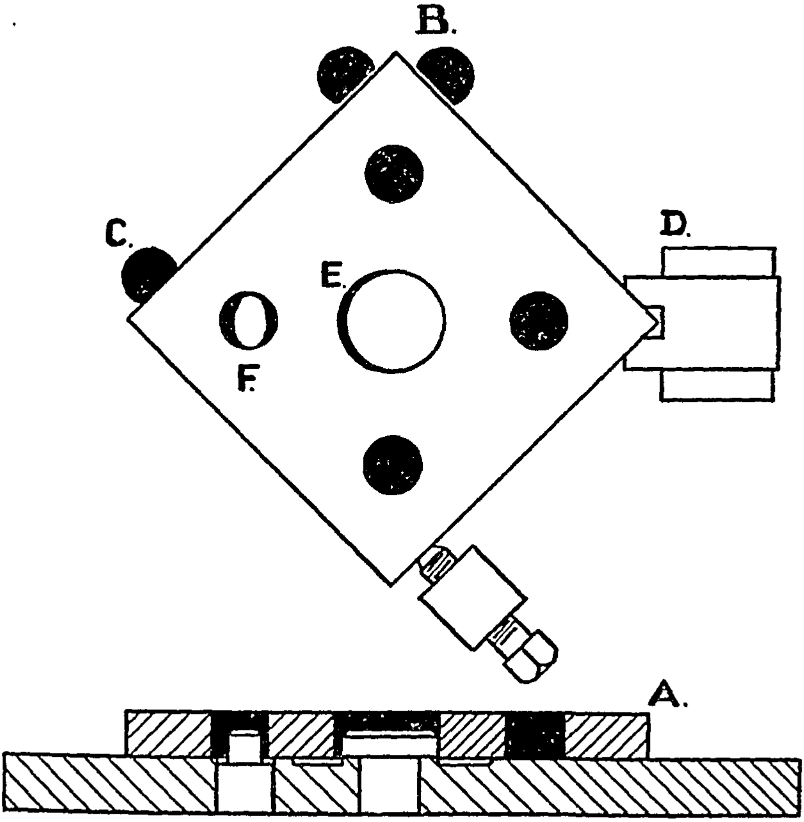


FIG. 60. A RECTANGULAR BED PLATE

locating some forms of universal coupling where there is a cross-pin, for notched bars and so on.

Fig. 60 has been devised with the idea of pressing home some of the points which have already been raised and a few fresh ones. Consider first of all the square plate A before it had been pierced by five holes. In that state it belongs to Group 1, and would be given the matchbox location. But supposing the width of the square varied

$\frac{1}{32}$ inch up and down. The side and end stops should then either be fixed at the mean or be what is called "fixed adjustable." A fixed adjustable stop can be varied to suit a run of components of one size and easily changed when another batch is slightly different. An imaginary objection to this stop is that workmen will carelessly set it wrongly. It economizes in tool-making and is widely used.

A more elaborate way of allowing for variations would be a right- and left-hand screw device. It would be out of place in this instance, and if the large hole had to be dead central, the sides of the square would be machined. Here they are supposed to be rough.

Now suppose that the centre hole has been bored and it is desired to locate the plate for drilling the small ones. For this purpose it should belong to Group 3. At B there are two peg stops which will position one corner roughly. The component will be able to move a little between them unless it is held firmly by the friction due to clamping. Hence it really belongs to Group 2 if located in that manner. Quite a useful hybrid it is, too.

Now discard B and use stop C. Opposing that is a clamping screw. This makes a firm job, but—how about the variations in the size of the square? Replace C by a fixed adjustable stop and that is taken care of, nearly. Near enough, perhaps, but perfection has not been attained. At D is something still better, a sliding vee which automatically equalizes the corner.

But observe what has happened at E: the component has been pushed bodily over, all the slack of the spigot fit being on one side. How elusive is perfection!

When the small holes are in, another method, as shown at F, can be used. The oval dowel is one of the most useful devices, but its failing is the same as at B—there is slack in the fits and consequent uncertainty, but not sufficient to worry about for most purposes.

The sliding vee (and the wedge) used for subsidiary

ocation as at D in this example may be regarded as combining within itself the function of a stop and a clamp. Each arm can be either. But this is academic and need not be pursued further. It is mentioned because otherwise seven-stop location would be practicable, which it is not.

Experiment to Demonstrate Inaccuracy in Simple Tools.

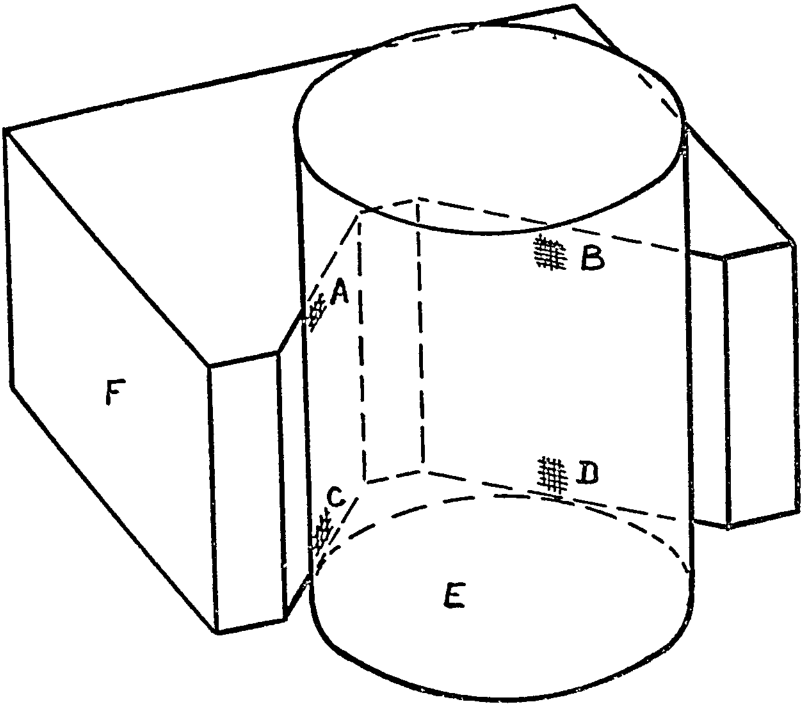


FIG. 61

Take a cylinder which has been turned and end faced. One about two inches diameter and three or four inches long will do well. Place it upright on a surface plate. It may rock unless the end has been slightly dished, and rocking will not do. A vee block is needed, too, the best available, provided it is not less than, say, 2 inches wide. Place the block against the cylinder as shown by F and E in Fig. 61. Now cut two strips of notepaper about ¼ inch

wide and hold them so that one piece is nipped at A and B and the other at C and D, at the shaded spots.

Well, it is a good vee block, wide enough for AB to be nearly two inches from CD; the cylinder has a nicely faced end; and the plate was carefully scraped some time

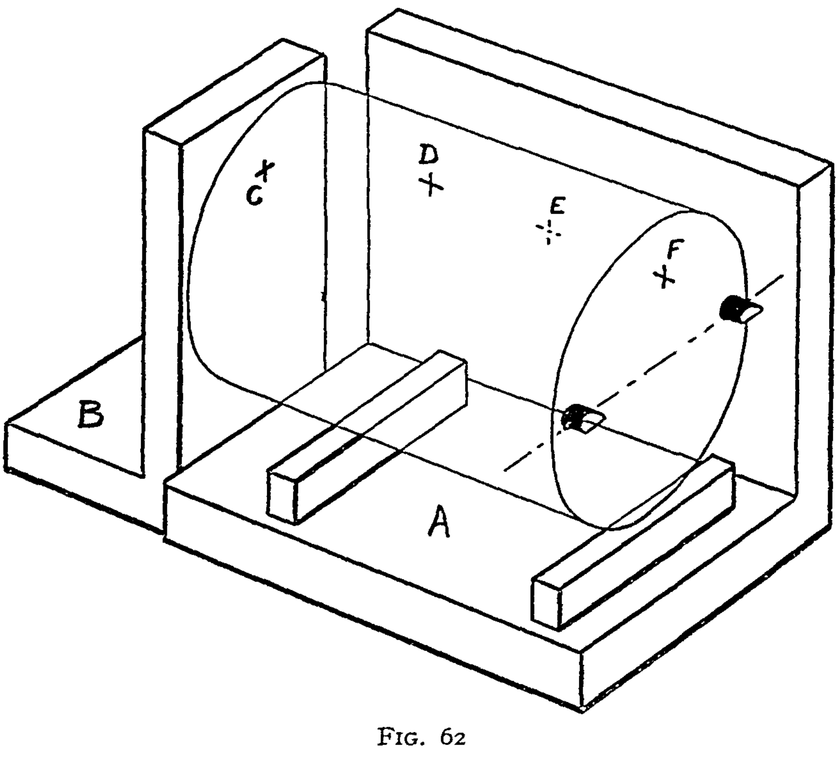


FIG. 62

ago. Yet the paper cannot be nipped at all four spots simultaneously unless either the block or the cylinder is tilted on the plate. Strain! Group 2 location. Can one be sure of this? Practically, but not absolutely. If notepaper does hold, try cigarette paper instead.

In practice, therefore if the surface plate is to be the base, the vee block should be narrow, reducing the effective stops to two small ones instead of two large or four small ones. Group 2 perfectly. But if the vee is to form the base, insert a small coin between cylinder and plate, Group 4.

With the surface-plate base the narrow block should be close to it but not in contact. When there is no gap, awkward corners are left which harbour dirt.

Experiment to Test the Six-stop Principle. For the next experiment refer to Fig. 62.

Two angle plates A and B are arranged as shown and A has a pair of parallel strips on it. Place the cylinder used in the previous experiment on them so that it can roll. Press it against stops C, D, F, and there is Group 4 location—five stops, and nothing to prevent twist except friction. If the cylinder has been turned truly parallel, the stop E, level with D, F, will contact equally with them. If E is the least shade proud or the cylinder is ever so little barreled, there will be rock. But, and this is of practical importance, if the cylinder were long and slender, likely to bend by clamping intermediately, it could be "felt up" to the stops D, F without appreciable yielding. Then E (being adjustable) could be screwed forward to make a light but firm contact. After that the clamp could be tightened without injuring the cylinder. This is only an illustration of the use of auxiliary supports or stops, and in this particular case there are other ways which could be used.

Now mark off a diameter across one end of the cylinder, using vee block and a scribing block. Raise the point $\frac{3}{32}$ inch and mark another line parallel with the first. With their centres on the second line, at opposite ends, drill two $\frac{1}{4}$-inch diameter holes parallel with the axis of the cylinder. Drive in a couple of pegs and file flats which lie exactly (if possible) on the diameter first scratched.

Replace the cylinder on the strips and ascertain its exact height to the top. Calculate from this the height of the axis from the surface plate. Build up gauge blocks or file a rod exactly to correspond with this height and twist the cylinder until one flat rests on it. Group 5 location. Without disturbing the cylinder, slide the

gauge to the second peg (or better, use two gauges). Does it contact? NO! There are four contacts on the vee, an end stop and the first peg, six stops altogether. The second peg makes the seventh. It cannot contact without strain or—a fluke.

Still, two lugs under precisely the above conditions are often made to contact simultaneously by a balancing device which will ensure that each takes half the total pressure and that the error in placing is divided equally between them. A little consideration will show that in that case the real, and single, stop is the fulcrum about which oscillation occurs.

This brief account has merely indicated a few examples here and there of the way accuracy is impaired by the instability or flexibility of the materials used in engineering production. The fundamental principles of location in jigs and fixtures have been outlined; and if to some the account appears rudimentary it is hoped that the manner of it may make it at least refreshing.

In view of the many difficulties which have been mentioned one may anxiously inquire whether good work can ever be done. Yes; provided one knows what troubles to expect and how to avoid or cure them. That is being an engineer.

Then it should be remembered that what would be intolerable in some kinds of work would not be noticeable in its effect on others. Do not expect praise for working to a thousandth of an inch when a hundredth is near enough.

INDEX